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STATEMENT

The undersigned, an attorney registered to practice before the office, hereby states that the enclosed substitute specification includes the same changes as are indicated in the mark-up copy of the original specification. The substitute specification contains no new subject matter.

Respectfully submitted,

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CERTIFICATE OF MAILING

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METHOD AND DEVICE FOR CONTROLLING OR REGULATING MOTOR VEHICLES

Technical Field

The present invention pertains to improvements in controlling or regulating motor vehicles. [The aspects cited in this application may be applied individually in combination. Certain advantages are achieved with combined applications.]

[A first aspect of the present invention pertains to a method and device for controlling or regulating a motor vehicle in accordance with the preambles of Claims 1 and 10.]

Background of the Invention

In modern methods or systems for regulating motor vehicles, various components are utilized which, in particular, are able to influence the control of the longitudinal dynamic (acceleration and respective deceleration in the driving direction) in order to assist the driver who had to perform this task by himself until now:

the speed regulator that is controlled by the driver (cruise control),

a motor vehicle follower control for monitoring and maintaining or adjusting the distance to the vehicle directly ahead,

dynamic curve controls that also influence the speed and acceleration in the driving direction,

engine/transmission controls that regulate the engine with respect to technical/economic/ecological principles, and

brake controls, e.g., distance-aided brake assistant, analog brake assistant.

The above-mentioned listing of system components certainly is not exhaustive at this time. These components predetermine nominal values for the acceleration and/or the speed which are respectively determined in accordance with their criteria. Consequently, it is necessary to coordinate the various sources for nominal values in order to control the engine and the brakes in suitable fashion.

One known example of such a coordination is the interaction between the desires of the driver (gas pedal), the cruise control, and the motor vehicle follower control. Here, the motor

vehicle follower control predetermines, if so required, suitable nominal speeds for the cruise control such that the motor vehicle follower control is able to reach its control target. This means that the motor vehicle follower control is connected in series with the cruise control. The desires of the driver, i.e., actuation of the gas pedal, are usually incorporated into the system in such a way that they override the automatically generated signals. The longitudinal dynamic control system is switched off when the brakes are actuated.

The aforementioned system and respective method have the disadvantage that the dynamic behavior of the follower control cannot be better than that of the cruise control. It was determined that the dynamic behavior is inadequate.

The object of this aspect of the invention consists of disclosing a method and a device for controlling a motor vehicle which make it possible to determine suitable reference variables for the motor vehicle control.

[This object is realized by the characteristics of Claims 1 and 10. The dependent claims pertain to preferred embodiments of the invention.]

In order to achieve a sufficient dynamic, the control interventions according to the invention are not realized via the speed controller, but rather, directly, i.e., comparable to the driving interventions of braking and accelerating. These driving interventions alter the longitudinal acceleration of the motor vehicle in the form of a control variable; the longitudinal acceleration is selected as the control variable.

[Individual embodiments of the invention are described below with reference to the figures, wherein:]

Brief Description of the Drawings

Figures 1 and 2 show a first embodiment of the invention.

Figure 3 shows a second embodiment of the invention.

Figure 4 shows one possible design of the monitor in Figures 2 and 3.

Figure 5 shows one embodiment of the acceleration controller, wherein the monitor is omitted so as to provide a better overview.

Figure 6 shows one embodiment of the braking torque controller.

Figure 7 shows an embodiment of the engine torque controller.

Figure 8 shows another embodiment of the engine torque controller.

Figure 9 shows a time-dependency diagram for explaining the occurrence of spontaneous traffic jams.

Figure 10 shows a schematic representation of a distance controller.

Figure 11 shows waveforms for speed and the distance during the control according to one embodiment of the invention.

Figure 12 shows the spectrum of an unprocessed speed signal.

Figure 13 shows a basic block diagram of the invention.

Figure 14 shows an embodiment of the low-pass filter in Figure 13.

Figure 15 shows an embodiment of the band-stop filter in Figure13.

Figure 16 shows a spectrum of the filtered speed signal according to the invention.

Figures 17 and 18 show the output signal of the nonlinear filter according to the invention in comparison to the output signal of the ABS-control, and in comparison to linear filters with different cut-off frequencies.

Figure 19 shows a combination of several of the above-mentioned components which form a control strategy.

Figure 20 is a graph of nominal speed versus time.

Figure 21 is a depiction of an amplification gain characteristic.

Figure 22 is a depiction of two characteristic curves of function generator 5-15.

Figure 23 shows the general design of the pressure control according to the invention in the form of a block diagram.

Figure 24 shows an embodiment of a pressure monitor with a simple pressure controller.

Figure 25 shows the nonlinear monitor of a brake system.

Figures 26a and 26b respectively show the control circuit which corresponds to the nonlinear monitor in figure 25 and the linearized control circuit.

Figure 27 shows a block diagram of one embodiment of the combined control circuit.

Figure 28 shows a brake circuit, in which the system according to the invention is utilized.

Figure 29 shows a brake circuit that contains only one digital valve instead of the previously described two digital valves.

Figure 30 is a logic flow diagram of the method of the present invention.

Figure 31 shows the driving situation on which the method according to the invention is based, in terms of a model.

Figure 32 shows an embodiment of the control method according to the invention.

Figure 33 shows another embodiment of the control method according to the invention.

Figures 34a-34c show the progression of the most important driving variables during the control method according to the invention.

Figure 35 shows a flow chart of one embodiment of the method according to the invention.

Figure 36 shows the process sequence of one embodiment of the method according to the invention.

Figure 37 shows one embodiment of a controller according to the invention.

Detailed Description of the Preferred Embodiments

One embodiment of the invention is described below with reference to Figure 1.

Figure 1 shows an example of different sources for predetermining nominal values. The reference numbers 1-17a-c identify various sensors, based on the output of which nominal accelerations are generated. Reference number 1-17a designates a distance sensor that determines the distance to the vehicle driving directly ahead. A motor vehicle follower control 11a determines a suitable motor vehicle acceleration for the motor vehicle follower control based on the signals output by the sensor 1-17a. Reference number 1-17b designates pushbuttons that are located on the steering wheel or a steering column switch for influencing the cruise control. The pushbuttons may consist of switches for setting, increasing, decreasing or resuming a certain nominal speed. The cruise control 1-11b determines an acceleration for reaching the desired control target based on the control input with the aid of the aforementioned pushbuttons or other operating restrictions. The driver is able to directly influence the motor vehicle by actuating pedals 1-17c (brake pedal and gas pedal, and, if applicable, the clutch pedal). A suitable control 1-11c determines an acceleration a_{pedal} from these variables as well as other operating conditions. Reference number 1-11d designates additional sources for intermediate acceleration values, e.g., a curve speed adaptation or a driving stability control.

According to the invention, it is proposed to functionally generate the individual nominal accelerations in parallel fashion by the respectively "responsible" components 1-11a-1-11d, wherein the generated nominal longitudinal accelerations are supplied to a coordination unit 1-12 in parallel, and wherein a resultant nominal longitudinal actuation a_{Lnom} is determined in suitable fashion in the coordination unit.

This acceleration a_{Lnom} is forwarded to an acceleration controller 1-13 that actuates different motor vehicle actuators, e.g., the brake 1-14a and/or the transmission 1-14b and/or the engine 1-14c, based on this acceleration.

Various designs of the coordination unit 1-12 are conceivable. For example, the coordination unit 1-12 can be simply designed in such a way that it forwards the smallest numerical value of all values input into the coordination unit to the acceleration controller 1-13 as the nominal value a_{Lnom}. In this case, the "smallest value" should be interpreted in the mathematical sense, i.e., by taking into consideration the preceding sign. However, the coordination unit 1-12 may also form a weighted average of all received values, wherein the weights may, if so required, be adapted or shifted depending on the given situation. The state variables in and around the motor vehicle are determined by means of sensors 1-16 and 1-17a-c. The values delivered by these sensors may be used for controlling the weight or the selection of individual nominal acceleration values input into the coordination unit 1-12.

The components 1-11a-d, which generate the individual nominal values, lie and consequently operate functionally parallel to one another. Consequently, it is possible to provide the individual components with different characteristics without the risk that such characteristics will be compromised by subsequent components. For example, it is possible to adjust the cruise control to "soft," wherein the distance follower control can be adjusted to "direct." In the system according to the invention, if signals from the cruise control 1-11b and the motor vehicle follower control 1-11a appear concurrently, the coordination unit 1-12 is able to select the acceleration a_{foll} output by the motor vehicle follower control 1-11a and feed this acceleration to the acceleration controller 1-13 as the acceleration a_{Lnom} without the risk that the "direct" characteristic of the motor vehicle follower control will be compromised by the "soft" characteristic of the cruise control 1-11b. In the initially described known example, the output result of the motor vehicle follower control would be evaluated by the downstage cruise control and possibly compromised.

The components 1-11a-1-11d that generate the nominal values are not limited to the previously described example. Additional refinements of the motor vehicle control may contain other components that individually generate nominal values. These additional components may be connected in parallel to the already existing components and incorporated into the coordination carried out by the coordination unit 1-12.

The entire system is monitored by a control and safety logic 1-18 that ensures the control sequence and, if individual components fail, is able to intervene by taking corresponding measures,

e.g., switching off part of the system, switching of the entire system, etc. An adaptation of different steady state characteristics to different classes of drivers is also possible by monitoring the behavior of the driver, the motor vehicle reaction and the ambient conditions. The control and safety logic 1-18 also controls and monitors the user interface 1-15 by exchanging signals with this unit.

Another aspect of the present invention pertains to a method and device for adjusting a predetermined nominal acceleration of the motor vehicle. In the mathematical sense, the term "acceleration" also includes negative values, i.e., driving conditions which are generally referred to as braking maneuvers.

A nominal acceleration may, for example, be predetermined directly by the driver or indirectly by an ICC-system (intelligent cruise control). In ICC-systems, nominal accelerations are, for example, not only determined based on the driver's intentions, but also in accordance with, for example, a motor vehicle follower control (controlling the distance to the vehicle directly ahead), a control for avoiding hazardous traffic situations, etc. For this purpose, motor vehicle state variables are determined by means of sensors (e.g., gas pedal, brake pedal, throttle sensor, intake air quantity, engine speed, transition gear ratio). In addition, external state variables, e.g., the distance to the vehicle directly ahead, the road conditions, as well as the general surroundings and stationary obstacles are, if so required, determined by suitable sensors and evaluation units. An ICC-system determines a nominal longitudinal acceleration to be adjusted for the motor vehicle based on the internal and external variables.

In known acceleration control methods, a differentiation of the measured motor vehicle speed is carried out as part of PI or PID controls in order to determine the actual acceleration. This differentiation is associated with conventional problems, e.g., a large noise component when using differential quotients or a large phase-shift when using a differentiating filter. Since stability reserves must be observed when differentiating and filtering the speed signal, the adjustable dynamic of the control circuit is comparatively low. In addition, the control parameters depend on the mass, speed, engine performance data, etc., where the determination of the parameters takes place in comparatively complex fashion.

The objective of these partial aspects of the invention consists of disclosing a method and a device for controlling the acceleration which make it possible to carry out faster acceleration control in more reliable and more robust fashion.

[According to the invention, this objective is attained with the characteristics of the independent Claims 19 and 31. The respective dependent claims pertain to preferred embodiments of these partial aspects of the invention.

Individual embodiments of these partial aspects of the invention are described below with reference to the appended figures, wherein:

Figure 2 shows a first embodiment of these partial aspects of the invention,

Figure 3 shows a second embodiment of these partial aspects of the invention,

Figure 4 shows one possible design of the monitor in Figures 2 and 3,

Figure 5 shows one embodiment of the acceleration controller, wherein the monitor is omitted so as to provide a better overview,

Figure 6 shows one embodiment of the braking torque controller,

Figure 7 shows an embodiment of the engine torque controller, and

Figure 8 shows another embodiment of the engine torque controller.]

The general concept as well as a first embodiment of these aspects of the invention are described below with reference to Figures 2 and 3.

The invention proposes a model-based control system. Estimated values for the braking torque $T_{brake,est}$ and the engine torque $T_{engine,est}$ are determined from the input variables measured by sensors based on models. Consequently, these estimated values are based on actually measured motor vehicle variables. In addition, a nominal drive torque T_{nom} for reaching the desired nominal acceleration a_{nom} is determined. This means that the nominal drive torque T_{nom} reflects the control variable a_{nom} of the control system according to the invention.

In Figure 2, reference number 2-10 designates a device for converting the nominal acceleration a_{nom} into a nominal drive torque T_{nom}. This device represents a prefilter. In the simplest instance, the conversion from nominal acceleration into nominal torque may consist of a proportional conversion. However, dynamic portions may also be taken into consideration, e.g., by means of a dynamic compensation of system response times. The device 2-10 outputs the nominal drive torque T_{nom}.

Reference number 2-11 designates a device for modeling a motor vehicle brake or, in simpler terms, a brake model. The brake model 2-11 receives the measured main cylinder pressure as the input variable and estimates its total braking torque. However, the effects of an antilock braking system (ABS), a wheelslip control system (ASR), or an automatic stability management system (ASMS) may also be incorporated. Instead of measuring the brake pressure, an estimated brake

pressure may also be derived from control signals for actively generating the brake pressure (e.g., with an active booster).

Reference number 2-12 designates a device for modeling the engine/transmission. This model delivers the estimated engine torque $T_{engine,est}$ as the output variable. The input variables received by this model consist of the motor vehicle speed v_{abs}, the engine speed $n_{act\,t}$, and the throttle angle $\propto_{act}$. Based on these input variables, the device 2-12 estimates the drive torque resulting on the wheel. The model may contain parts or all of the engine performance data used in an engine control system.

In modern engine control systems, the torque delivered by the engine is frequently available in the form of a signal. In this case, a transmission model suffices for estimating the engine torque. This variation is shown in Figure 3. In this figure, the engine/transmission model 2-12 according to Figure 2 is replaced with a transmission model 2-22 that receives the transmission gear ratio i as well as the engine torque T_{act} predetermined by the engine control system as input variables. Based on these input variables, the drive torque on the wheel $T_{engine,est}$ is determined. If the gear ratio of the transmission is known in the control system, the torque on the wheel can be easily calculated.

The monitors shown in Figure 2 and Figure 3 respectively consist of a device 2-13 and 2-23 for modeling the behavior of the motor vehicle. In this case, the input variables consist of the braking torque $T_{brake,est}$ determined with the aid of the brake model, the drive torque on the wheel $T_{engine,est}$ determined with the aid of the engine/transmission model as well as the motor vehicle speed v_{abs}. The monitor may be specifically designed for the respective type. In this case, the monitor recognizes certain motor vehicle parameters, e.g., the motor vehicle mass, the dynamic wheel running radius, motor vehicle time constants, etc. Figure 2 shows an instance in which the signal output by the monitor is the torque $T_{actual,est}$ acting on the motor vehicle.

However, it would also be conceivable to alter only the nominal motor vehicle torque with the output variable of the monitor. In Figure 3, a correction torque T_{corr}, referred to the motor vehicle speed v_{abs}, is determined with the aid of the estimated values for the braking torque $T_{brake,est}$ and the engine torque $T_{engine,est}$. The nominal torque T_{nom} is corrected with this correction torque T_{corr}. Based on the result of the correction, the engine and/or brakes of the motor vehicle are controlled by means of suitable actuators.

From this design of the acceleration control, the correction required for reaching the nominal value is determined with the aid of the motor vehicle speed v_{abs}, but not its differentiated value. Consequently, the previously described serious disadvantages of known acceleration controls can

be eliminated. The device 2-23 delivers the correction torque T_{corr} as the output variable, wherein the nominal torque T_{nom} determined from the nominal acceleration a_{nom} is corrected with said correction torque. Initially, the motor vehicle speed v_{est} is estimated in the device 2-23 with the aid of the estimated values for the engine torque (drive torque on the wheel) T_{engine} and the braking torque T_{brake}. This estimated value is compared with the measured motor vehicle speed v_{abs}. Based on the deviation between the measured speed v_{abs} and the estimated speed v_{est}, the correction torque T_{corr} is determined and output by the device 2-23.

The torque controllers 2-14 and 2-24 respectively receive the nominal torque T_{nom} from the prefilter 2-10 (and the prefilter 2-20) and the correction torque T_{corr} and the actual torque $T_{actual, est}$, the actual torque $T_{actual,est.}$ and the correction torque T_{corr}) from the respective monitors 2-13 and 2-23 as input variables. Control signals for actuators are determined on the basis of these two input values. These control signals may consist of:

control signals for the throttle in order to increase or decrease the throttle opening angle,

control signals for the brake in order to increase or decrease the brake pressure, and, if applicable,

control signals for the transmission in order to adapt the transmission stage if so required.

According to Figure 3, the nominal torque T_{nom} and the correction torque T_{corr} are simply added, wherein suitable measures, e.g., either an adaptation of the fuel supply signal or the brake pressure, are taken on the basis of the preceding sign. The values of the nominal torque and the correction torque may, however, also be processed such that a weighted average is formed.

Figure 2 shows that a control signal may also be generated in 2-14 based on the output signal of the monitor 2-13 and the prefilter 2-10. The control signal is fed to a coordinator that converts the control signal into a third and fourth signal, e.g., in dependence on its preceding sign. The third and fourth signals are respectively used for generating an acceleration and a deceleration correction variable.

In Figure 3, the reference number 2-25 designates a braking torque controller. This braking torque controller receives its input signal $T_{brake,nom}$ from the block 2-24. The braking torque controller also processes the estimated braking torque T_{brake}. The braking force can be regulated on the basis of these two values. The controller outputs a signal p_{nom}, with which a suitable controllable pressure source can be controlled. Since the brake hydraulic system is known in comparatively precise fashion, a feed-forward portion in accordance with the inverse brake model can also be incorporated.

In Figure 3, reference number 2-26 designates an engine torque controller. This engine torque controller receives its input signal $T_{eng,nom}$ from the block 2-24. This engine torque controller also processes the estimated engine torque T_{engine}. A control of the engine torque is possible on the basis of these two values. The controller outputs a signal $T_{nom,out}$ or $\propto_{om}$.

Figure 4 shows combined embodiments of the brake models 2-11 and 2-21, the engine model 2-12 and transmission model 2-22, and the internal design of the monitors 2-13 and 2-23, respectively.

The respective brake models 2-11 and 2-21 are realized with an amplification device 2-30 and a low-pass filter 2-31.

The engine model 2-12 consists of an amplification device 2-32 that is realized in nonlinear fashion in Figure 4, namely as an approximation to an engine performance graph, a low-pass filter 2-33 that may be realized in the form of a PT_1-element and a device 2-34 for simulating the transmission gear ratio.

The monitor consists of a device 2-35 that proportionally simulates the wheel radius r and the motor vehicle mass m in the embodiment shown (2-35), as well as an integration element 2-36. A sensor signal delay and the force build-up on the tire (2-37 and 2-38, in this case, a single-pole low-pass filter), which is simulated by means of feedback, are connected in series with this integration element. The speed v_{est} estimated by the monitor is output as the result. This estimated speed is compared with the determined motor vehicle speed v_{abs}. Based on this comparison, the correction torque T_{corr} and the torque $T_{actual,est}$ acting on the motor vehicle are determined and output.

Figure 5 shows combined embodiments of the prefilter 2-20 and the coordinator 2-24 according to Figure 3. The motor vehicle mass m and the wheel radius r are simulated with the device 2-40--the prefilter--which receives the nominal acceleration a_{nom}. The device 2-40 delivers the nominal torque T_{nom}. In the embodiment shown, this nominal torque is added (2-45) to the correction torque T_{corr} (that may also be negative) in the coordinator 2-24 such that a control torque T_{ctl} results. Whether the control torque T_{ctl} is positive or negative is determined by the decision device 2-41. If the control torque is positive ($T_{ctl} > 0$, lower branch), the engine torque controller 2-43 is actuated. If the control torque is negative ($T_{ctl} < 0$, upper branch), the braking torque controller 2-42 is actuated.

Figure 6 shows an embodiment of the braking torque controller. Its output signal consists of a nominal pressure p_{nom} for the brake force actuator. The input signal received by the braking torque controller in the nominal braking torque $T_{brake,nom}$ that is compared with the estimated braking

torque T_{brake} from the brake model and then gradient-limited (2-52). A feed forward portion 2 51, for compensating the comparatively well known behavior of the brake system beforehand, is connected in parallel to the comparison between the nominal braking torque and the estimated braking torque. The I-portion of the signal p_{nom} is set to zero if the throttle is not yet entirely closed, so as to force a permanent deviation of the braking torque. Due to this measure, it is possible for the engine torque controller to entirely close the throttle once the brakes are actuated, i.e., it is possible to prevent an instance in which the brake and the engine are working against each other.

Figure 7 shows an engine torque controller (corresponding to 2-26 in Figure 3). The coordinator (2-24 in Figure 3 and 2-41 in Figure 5, respectively) outputs a nominal engine torque $T_{eng,nom}$ that is subtracted from the estimated engine torque T_{engine} determined with the aid of the engine model 2-12. The result passes through a PI-controller (2-62 and 2-63) which is gradient-limited. A feed-forward portion 2-61 may also be incorporated in this case in order to improve the control dynamic.

Figure 8 shows a variant of the engine torque controller, which is suitable for a highly developed engine electronic system, in which the current engine torque is known. This actual value is then used for the control. The output value of the engine torque controller is the nominal engine torque value for the engine electronic system.

The individual components shown in Figures 2-8 may be realized by means of the corresponding circuits and characteristic diagrams. The individual components are preferably realized in the form of correspondingly programmed computers, i.e., discrete-time digital systems which operate at a suitable sampling frequency of the individual values.

Another aspect of the present invention pertains to a method and a device for realizing a motor vehicle follower control.

A frequently recurring problem in modern road traffic is traffic jams on busy roads for no apparent reason. Specifically, such traffic jams occur when the individual speeds of motor vehicles driven behind one another are not determined by the intentions of the respective drivers but by the speed of the vehicle ahead. The occurrence of such traffic jams is described below with reference to Figure 9.

Figure 9 shows speed plots for different motor vehicles. Curve 3-10 shows the speed of a given motor vehicle, and curve 3-11 shows the speed of the motor vehicle following immediately behind the first. The following explanation is based on the steady state, in which one motor vehicle drives behind the other at a constant speed v_0. It is assumed that the first vehicle decelerates at time

t_1 and then continues to drive at the reduced speed v_1. Consequently, curve 3-10 shows a decrease in speed from v_0 to v_1 beginning at time t_1. This results in a condition in which the speed of the second vehicle (curve 3-11) is greater than the speed of the first vehicle (curve 3-10) beginning at time t_1. In order to prevent a rear-end collision, the second vehicle must eventually decelerate. However, the second vehicle is unable to immediately follow the change in speed of the first vehicle or the distance control system. In this case, at least the reaction time of the driver of the second vehicle passes until the second vehicle also reduces its speed at the time t_2. The speed of the second motor vehicle is greater than that of the first motor vehicle up to the time t_4, at which time the speed of the second vehicle is adapted to that of the first vehicle. Consequently, the distance between both motor vehicles is reduced up to time t_4. The reduction in distance corresponds to the surface (integral) between the two curves. This means that the distance between the two motor vehicles was reduced up to time t_4. In order to compensate for this reduction, the second vehicle is also decelerated. This is usually realized by reducing the speed until the original distance between the two motor vehicles or a distance between the two motor vehicles which corresponds to the new speed is adjusted. In Figure 9, this is assumed to occur at time t_5. Between times t_4 and t_5, the speed of the second vehicle is slower than that of the first vehicle, i.e., the distance between both vehicles is increased again. The area 3-14 between the two curves 3-10 and 3-11 corresponds to the increase in distance. Once the original distance is restored, the acceleration process begins so as to adjust the speed to that of the first vehicle. Since the speed of the second vehicle is still lower than that of the first vehicle beginning at time t_5, the distance between both motor vehicles is additionally increased until both motor vehicles travel at the same speed at time t_6. The additional increase in distance corresponds to the area 3-15. At time t_6, the distance is greater than before time $t_{[illegible]}$ by this amount. This lost distance can be compensated (approximately between times t_7 and t_8) if the second vehicle travels faster than the first vehicle.

This means that there are periods in which the speed of the second vehicle is less than that of the first vehicle. In the described embodiment, this is the case between times t_4 and t_6. If a third vehicle travels behind the second vehicle, processes similar to those between the two initially observed vehicles will occur between the second and third vehicles. This results in the third vehicle assuming a minimal speed that will be slower than the slowest speed of the second vehicle. This is schematically indicated by the curve 3-12 in Figure 9. This means that these processes are added up until the traffic comes to a complete standstill.

In this case, it does not matter whether the vehicles are freely controlled by the respective drivers or an ICC-control (intelligent cruise control) takes place. An ICC-control also has reaction times, i.e., the distances between one motor vehicle following another will be reduced if the lead vehicle decelerates. Such reductions in distance are compensated by decelerating the trailing vehicle to a speed that is less than the speed of the lead vehicle as described with reference to Figure 9.

The object of this aspect of the invention consists of disclosing a method and a device for controlling the driving speed which eliminate or prevent the effects of reaction times or delay times.

[This object is realized with the characteristics of the independent Claims 43, 44, 47, and 48, wherein the respective dependent claims pertain to preferred embodiments of this aspect of the invention.

Individual embodiments of this aspect of the invention are described below with reference to the figures, wherein:

Figure 9 shows a time-dependency diagram for explaining the occurrence of spontaneous traffic jams,

Figure 10 shows a schematic representation of a distance controller, and

Figure 11 shows waveforms for speed and the distance during the control according to one embodiment of the invention.]

Figure 10 shows a distance controller. This distance controller receives input signals that are delivered by a highly developed sensor arrangement. Among other things, the distance controller receives signals that indicate the distance between a given motor vehicle and the vehicle immediately ahead, as well as the relative speed between the two vehicles. In addition, the controller recognizes the speed of the motor vehicle. The controller is designed for generating control signals for the motor vehicle from at least the above-mentioned input signals. These control signals may contain control signals that lead to an acceleration as well as a deceleration of the motor vehicle. An acceleration of the motor vehicle occurs if the distance controller outputs signals that, for example, correspond to the digitized signals of the gas pedal. These output signals are then processed in suitable fashion by a downstage engine controller. However, direct actuating signals for the throttle would also be conceivable, if so required, in connection with signals for the injection period in order to directly increase the speed. A reduction in the motor vehicle speed can also be realized by means of gas pedal signals and throttle signals (engine brake). In addition, the ICC-controller may output signals that lead to an active deceleration of the motor vehicle, due to the fact that the brake system is directly or indirectly actuated.

The problem of a spontaneous bumper-to-bumper traffic jam, which was described with reference to Figure 9, can be rendered less severe due to the fact that when one motor vehicle drives behind another, the speed of the second vehicle is controlled such that either it does not exceed the speed of the first vehicle or its appropriate safety driving distance at a given speed is adjusted with allowance for a time delay. In the meantime, a reduced distance between the motor vehicles is accepted. This results, for example, in the speed and distance waveforms shown in Figure 11. The curve 3-30 shows the speed of the first vehicle, and the curve 3-31 shows the speed of the second vehicle. Qualitatively, the curve 3-30 corresponds to the curve 3-10. A time delay between the beginning of the deceleration of the first vehicle and the beginning of the deceleration of the second vehicle cannot be avoided, even with the most modern technology. However, the ICC-control is able to predetermine suitable control targets in order to prevent the negative effects which occur in Figure 9. Figure 11 shows an instance in which the ICC-control controls the speed of the second vehicle (curve 3-31) in such a way that the second vehicle is decelerated with a certain time delay after the first vehicle was decelerated, wherein the speed of the second vehicle does not drop below of the speed of the first vehicle. Another control target consists of temporarily allowing shorter distances between the two vehicles as would be the case in the steady-state condition once the deceleration of the first vehicle is detected.

Figure 11 shows a control target in which the speed of the second vehicle cannot drop below the speed of the first vehicle. The speed of the second vehicle (curve 3-31) is higher than the speed of the first vehicle (curve 3-30) between times t_9 and t_{10}. Consequently, the distance between the two motor vehicles is reduced between the aforementioned times. The reduction in distance corresponds to the integral over the relative speed. The reduction in distance is shown in the lower portion of Figure 11. The reduction in distance in the upper portion graphically corresponds to the area between the curves 3-30 and 3-31, where the value is designated by $-\Delta$ in the lower portion. The separation between the motor vehicles was reduced by this value $-\Delta$ between times t_9 and t_{10}. Once the speeds of both vehicles are identical starting at time t_{10}, the separation remains constant, so that the negative effect explained previously with reference to Figure 9 is prevented for the time being. The speed of the second vehicle does not drop below that of the first, so that the effect is not cumulative, particularly if several vehicles drive one behind another.

Various preventive measures are conceivable as time progresses. Figure 11 shows an instance in which the first vehicle accelerates again (time t_{11}). Here, the ICC-controller may be

designed in such a way that the second vehicle does not follow the acceleration of the first vehicle until time t_{12}, i.e., with a certain time delay. It is then accelerated until it assumes the speed of the first vehicle at time t_{13}. The separation is then preferably identical to that before time t_9. The time delay t_{12} - t_{11} between the acceleration of the first vehicle and the acceleration of the second vehicle is preferably identical to the time delay between the beginning of the deceleration of the first vehicle and the beginning of the deceleration of the second vehicle.

If the first vehicle does not accelerate at time t_{11}, but rather continues with a constant speed, the ICC-controller may be designed so that it adjusts the speed of the second vehicle to a speed that lies slightly below the speed v_1 of the first vehicle. This slightly reduced speed is preferably predetermined after a certain time period has passed, once the lower constant speed v_1 has been assumed (time t_{10}). This reduced speed is maintained at the speed v_1 until the desired separation between the two vehicles is reached.

If the predetermined control target is "the speed of the second vehicle cannot fall below that of the first vehicle," it can be checked whether, during deceleration of the second vehicle (before time t_{10} in Figure 11) the distance between the two vehicles drops below a minimum value that, if necessary, is speed-dependent and cannot be fallen short of. If the distance falls short of this minimum distance, the braking force may be increased and, if so required, the above-mentioned control target can be dropped, i.e., the speed of the second vehicle may fall below the speed of the front vehicle in this case. In this way, it is ensured that the ICC-controller is able to assist in preventing collisions.

The ICC-controller may also be designed in such a way that, if a deceleration of the front vehicle is detected, it temporarily allows a shorter distance between the two vehicles than in the steady-state condition. In this case, the controller may even permit shorter distances between the two vehicles for a period, during which the front vehicle has assumed a constant, slower speed after having decelerated. In Figure 11, this would be the speed v_1 beginning at time t_{14}. The minimum distances permitted in the steady-state condition or the permitted minimum distances in dynamic transient conditions may be a function of speed and be stored in tables or engine performance maps. Similar to the embodiment mentioned above, the distance assigned to steady-state conditions can be adjusted, after an additional time period has elapsed, by slightly decelerating the motor vehicle until the distance for steady-state conditions-and, if applicable, the appropriate distance for the corresponding speed is adjusted again between the two vehicles. An acceleration may subsequently take place until both vehicles have reached the same speed.

The above-mentioned control may also be implemented with a suitably programmed computer that receives the above-mentioned input variables and delivers the described control signals. Such systems are designed to carry out discrete-time sampling, in which the signal processing is done digitally.

Another aspect of the present invention pertains to a method and device for generating a speed signal that indicates the motor vehicle speed.

A precise speed signal is required for various tasks in controlling or regulating motor vehicles. Until now, the speed signal was either delivered directly by a sensor or obtained from the output of an ABS-controller. However, such signals are noisy, so that they cannot be easily utilized for some applications, e.g., in ICC-systems.

The objective of this aspect of the invention consists of disclosing a method and device which make it possible to obtain a precise speed signal with only a slight time delay.

[This objective is attained with the characteristics of Claims 51 and 60. The respective dependent claims pertain to preferred embodiments of the invention.]

While investigating the above-mentioned problem, the inventors determined that noise is not evenly distributed over the frequency range of the speed signal, but that individual noise components which can be discriminated are present. The inventors determined, in particular, that portions that can be localized in a certain frequency band, as well as portions at higher frequencies, interfere with the speed signal. One frequency band that is particularly noisy lies in the range of f_0 = 1 to 4 Hz, besides frequencies beginning at approximately f_1 = 8 Hz, which are very noisy.

[Individual embodiments of the invention are described below with reference to the figures, wherein:

Figure 12 shows the spectrum of an unprocessed speed signal,

Figure 13 shows a basic block diagram of the invention,

Figure 14 shows an embodiment of the low-pass filter in Figure 13,

Figure 15 shows an embodiment of the band-stop filter in Figure 13,

Figure 16 shows a spectrum of the filtered speed signal according to the invention, and

Figures 17 and 18 show the output signal of the nonlinear filter according to the invention in comparison to the output signal of the ABS-control, and in comparison to linear filters with different cut-off frequencies.]

Figure 12 shows the spectrum of a speed signal as it is conventionally utilized for controlling the engine and the motor vehicle, respectively. The spectrum which lies between the frequencies

0 and 5 Hz shows a defined peak at slightly below $f_0 = 2$ Hz. Such interference significantly influences the accuracy and thus the reliability of the motor vehicle control, and thus must be suppressed.

Figure 13 shows a block diagram of an embodiment according to the invention for suppressing interference of the speed signal. In this block diagram, the input speed signal v_E that is subject to interference passes through a low-pass filter 4-20 as well as a band-stop filter 4-21. In this case, it is not absolutely necessary to provide both filters 4-20 and 4-21. One of the two filters may suffice, where the series-connection of both filters--if so required in the reverse sequence--provides very good results.

In one preferred embodiment, it is taken into consideration during the filtering of the input speed signal v_E that the acceleration of the vehicle can lead to speed changes in the input signal that is subject to interference, where the order of said speed changes is comparable to or higher than the interfering ripple components in the signal. Components of this type cannot be simply filtered out, because the filtered signal would otherwise incorrectly reflect the speed or merely reflect the speed in delayed fashion.

Embodiments of the low-pass filter 4-20 and the band-stop filter 4-21 according to Figure 13 are described below with reference to Figures 14 and 15. Figure 14 shows an embodiment of the low-pass filter 4-20 according to the invention. For example, this component consists of a single-pole low-pass filter PT_1. It is formed by the gain K 4-30 and 4-34 as well as the integrator 1/s 4-31.

In one preferred embodiment, a gradient limitation 4-32 defines the range within which changes in the input speed signal v_E may occur. In this context, the term gradient limitation refers to a limitation of the rise or fall time of a signal. However, one encounters the problem that these changes may by far exceed the ripples during accelerations. If no additional measures are taken, the filter will cut off parts of the useful signal. Consequently, an additional PT_1-element 4-33 is connected in parallel to the gradient limitation 4-32. The PT_1-element delivers an offset that is added to the output of the gradient limitation 4-32. Due to this measure, the permissible ripples follow the respective acceleration level. The cut-off frequency of the additional PT_1-element 4-33 is preferably higher than that of the total transmission of the low-pass filter 4-20.

Figure 15 shows an embodiment of a band-stop filter. This band-stop filter is designed in such a way that the interference frequency is simulated (series integrators 4-43 and 4-44 and negative feedback 4-45). The amount of feedback 4-45 is adapted to the center frequency $\omega_0 = 2\pi f_0$

of the interference frequency band. The simulated interference frequency $\omega_0$is subtracted from the input speed signal v_Z at the point 4-40. Due to this subtraction, one obtains the output speed signal v_A that is also fed back into the simulation of the interference frequency $\omega_0$via blocks 4-41 and 4-42. The feedback of the output speed signal v_A into the simulation of the interference frequency ω_0 takes place in such a way that the signal passes through adjustable gains K1 4-41 and K2 4-42, respectively, and is additively fed in front of the respective input of the serially connected integrators 4-43 and 4-44. Due to this measure, the interfering frequency band is filtered out, and the circuit according to Figure 15 acts as a band-stop filter.

Due to the filtering of the original signal v_E, a speed signal v_A that is well suited for the additional processing is generated. This means that higher frequency portions are not randomly filtered. Such a random filtering would lead to accelerations of the motor vehicle which represent portions of higher frequency within the frequency range of the speed signal being rounded in the speed signal, i.e., a poorly adapted signal or a signal that would slowly follow the actual conditions would be delivered. The embodiment of the low-pass filter with gradient limitation 4-32 and offset feed 4-33 results in a nonlinear filter, with which permissible acceleration levels can be rapidly and reliably illustrated in the filtered signal despite the filtering out of ripples. The cut-off frequency of the low-pass filter is permanently adjusted and determined by means of comparisons with linear filters with different cut-off frequencies. The described band-stop filter according to the invention can be adapted to the respective conditions with the factors K1 and K2 by means of feeding the output signal v_A.

Figure 16 shows the spectrum of a speed signal that has passed through a band-stop filter according to Figure 13 and 15, respectively. One can clearly ascertain that the interference at approximately 2 Hz is eliminated.

Figures 17 and 18 respectively show a general overview and a detail of the output signal of the nonlinear filter according to the invention in comparison to the output signal of the ABS-control and in comparison to linear filters with different cut-off frequencies. Figure 17 shows a drive with an acceleration, a deceleration and a phase of uniform speed (constant drive at approximately 7 sec) over a period of approximately 25 sec. The time period around the maximum speed during these 25 sec is plotted in enlarged fashion in Figure 18. The signal with the most noise is the output signal of an ABS-controller. This signal is also the input signal for all other filters shown. The reference number NL designater the output signal of the nonlinear filter according to the invention. This

signal is much smoother than the ABS-signal. In addition, the output signal of linear filters with different cut-off frequencies (2 to 10 Hz) are also shown. One can ascertain that these filters also generate smooth output signal, but cause a greater phase shift or a higher attenuation than nonlinear filters. In this case, it must be observed that the nonlinear filter has a lower cut-off frequency (4 Hz) than the linear filter. The attenuation of the filter according to the invention corresponds to that of a linear 8 Hz filter. The ripple content of the nonlinear filter according to the invention is approximately comparable to that of a linear 2 Hz filter.

Another aspect of the present invention pertains to a method and a device for controlling motor vehicles. This aspect pertains, in particular, to motor vehicle control systems, in which nominal speeds that are subsequently adjusted by a series-connected control are predetermined. Such speed adjustments may, for example, be realized with the aid of a cruise control. These cruise controls may be of comparatively simple nature. Such a simple cruise control consists of switches that serve for setting, increasing, decreasing, canceling or resuming nominal speeds. However, cruise controls may also be used in connection with more complex control systems. Such control systems are known as ICC (intelligent cruise control) systems. In such control systems, the motor vehicle speed is not only controlled based on values predetermined by the driver, but also in accordance with information which sensors obtain from the surroundings of the motor vehicle. This primarily pertains to distance sensors that determine the distance to the vehicles that might be driving ahead. However, this may also pertain to sensors that, for example, examine the road conditions.

The previously described control systems operate on the basis of the driver's intentions and based on information determined by sensors inside or outside the motor vehicle. They generate a nominal speed in the form of a control variable in many instances. However, motor vehicle accelerations or the distance to vehicles driving ahead may also be predetermined as control variables. These predetermined control variables may lead to operating conditions of the motor vehicles which are perceived as unpleasant by the driver in either case, e.g., abrupt accelerations, abrupt decelerations or jerky movement of the motor vehicle. This may, in particular, occur if sudden changes in the predetermined nominal speed take place. Until now, such changes in the nominal speed were incorporated into the controller as a control variable in unevaluated fashion. This means that the above-mentioned unpleasant driving conditions cannot be sufficiently prevented.

The objective of this aspect of the invention consists of disclosing a method and a device for controlling or regulating motor vehicles which allow pleasant driving conditions with few jerks.

[This objective is realized with the characteristics of the independent Claims 69 and 79. The respective dependent claims pertain to preferred embodiments of this aspect of the invention.]

Individual characteristics of this aspect of the invention are described below with reference to Figure 19. Figure 19 shows a combination of the different characteristics of this aspect of the invention which are described below.

The following measures may be taken in order to attain the above-mentioned objective of the invention:

abrupt jumps in the predetermined nominal speed may be smoothed out with respect to their progression over time;

temporal changes in the predetermined nominal speed can be limited. The gradient of the nominal speed is limited in this way . The limiting may be defined sectionally or by means of an engine performance map and also be subject to certain changes;

an acceleration can be predetermined in the form of a control variable depending on the difference between the nominal speed that was filtered as described above or the nonfiltered nominal speed and the actual motor vehicle speed;

known reactions of the system can be compensated beforehand by means of a feed-forward branch, and

the above-mentioned measures can be monitored by a control of higher order. They can be adapted by means of a teachable motor vehicle controller.

The above-mentioned characteristics are described in greater detail below.

Figure 19 shows a combination of several of the above-mentioned components <u>which form a control strategy</u>. This figure shows an embodiment in which the predetermined speed v_{nom} is input into the system according to the invention from the left. If not indicated otherwise, it is assumed in the following description that this predetermined nominal speed increases abruptly. This may, for example, be the case if the driver significantly increases the nominal speed by actuating the corresponding key on the steering wheel or the steering column switch several times. Such an abrupt increase is uncomfortable; it may lead to engine vibrations in many instances, and must be effectively prevented.

For this purpose, a rounding of the nominal speed increase is carried out. The rounding is carried out with a suitable device. One example is shown in Figure 19, illustrating the combination of the devices 5-10, 5-11 and 5-12. The circuit shown consists, in principle, of a low-pass filter. The device 5-11 may simply consist of an amplifier that is followed by an integrator 5-12. Due to

the negative feedback at the node 5-10, the progression PT_1 of the input nominal speed progression results as the output variable of the integrator in the example shown. Consequently, the abrupt increase in the nominal speed is smoothed out. The low-pass filter does not necessarily have to consist of a PT_1-element. On the contrary, PT_2-elements or conventional low-pass filter elements may be used. Figure 20 shows the output signal of the low-pass filter (output of the integrator 5-12) as it may be formed by a PT_2-element in response to an abrupt increase in nominal speed. The abrupt increase in the nominal speed from zero to a certain value (curve 5-20) is converted into a slow increase (curve 5-21).

An additional protection against unpleasant driving conditions can be achieved if a gradient limitation for the nominal speed is incorporated. A gradient limitation can be carried out separately or in connection with the previously described low-pass filter (e.g., PT_1-element or PT_2-element). The effect of the gradient limitation is initially described with reference to Figure 20. In this case, the term gradient refers to the change in nominal speed per time unit. Physically, this pertains to acceleration. Figure 20 shows the steepest gradient shortly after the beginning of the rise of curve 5-21, wherein this is represented by the tangent line 5-22. Its slope corresponds to the gradient. The higher the abrupt increase in nominal speed, the steeper the steepest rise of the curve 5-21. It may occur that the rise becomes excessively steep despite the filtering. Consequently, the same disadvantages as with the initially assumed ideal increase in the nominal speed ultimately result. This is prevented by limiting the gradient-- the slope of the tangent line 5-22--to a certain value that is not exceeded independently of the value of the abrupt increase in nominal speed. In one embodiment, this can be realized with a separate circuit. Figure 19 shows another embodiment. In this case, the gain 11 is limited. Consequently, the gain has a characteristic similar to Figure 21. The difference obtained from the device 5-10 consequently is only amplified up to a certain maximum value. The desired gradient limitation is achieved with the aid of the integrator 5-12 and feedback.

The gradient limitation may be adjusted differently for positive and negative accelerations by setting different break points in the characteristic of Figure 21. In addition, it may be desirable to permit a manipulation of the gradient limitation. For example, if the driver's intentions expressly indicate that an intense acceleration is desired-which, for example, is input by actuating the acceleration key several times-steeper gradients can be permitted; for example, by shifting the break points in Figure 21 away from the origin only in this case. A steeper rise in the predetermined nominal speed is then possible, and the motor vehicle accelerates more quickly. If this change was

caused by the driver, this change in the gradient limitation represents a direct result of the driver's actions for the driver.

In addition, it is possible to improve the driving comfort if the predetermined nominal speed v_{nom} and the actual speed v_{ref} are different--also, if an acceleration is necessary--the acceleration being predetermined on the basis of the difference between nominal and actual speeds. In Figure 19, this predetermination is realized by a function generator 5-15. In the embodiment shown, the function generator receives the difference between the output of the low-pass filter 5-10 to 5-12 and the actual motor vehicle speed. The difference $\Delta v = v_{nom} - v_{ref}$ is formed in the device 5-13. Consequently, the function generator 5-15 receives a value which corresponds to the difference between the filtered nominal speed and the actual speed. In accordance with its function, the function generator outputs an acceleration that can be used as a control variable. In contrast to Figure 19, it is also possible to input the unfiltered nominal speed into the device 5-13. Figure 22 shows an example of two characteristics that describe the function generator 5-15. The curve 5-41 shows a simple instance in which the output acceleration a_{nom} is proportional to the difference between nominal and actual. However, more complex progressions which, for example, are shown in the form of the curve 5-42, are conceivable. Different slopes make it possible to simulate vehicle handling that is empirically determined. This means that the control according to the invention results in vehicle handling that appears to be very natural. The characteristic in Figure 22 may be implemented in the form of a formula or be stored in a table.

An additional improvement in vehicle handling is attained if a feed-forward portion is added to a nominal acceleration that, for example, was determined as described above. Figure 19 shows an embodiment in which a feed-forward portion is added to the output of the function generator 5-15 in the adder 5-6. This feed-forward portion is generated from a signal that was sensed between the amplifier 5-11 and the integrator 5-12 via a filter 5-18 and corresponds to an acceleration value. An amplification as well as system characteristics may be incorporated into the characteristic of the filter 5-18 such that the utilization of the feed-forward portion allows a very spontaneous reaction to the driver's intentions while preserving the comfortable controller dynamic.

In addition, it is also possible to carry out long-term observation of the driver's activities by means of a device 5-19. For example, the frequency, duration and abruptness of accelerations and decelerations can be determined. These determined values can then be classified (e.g., "slow driver," "fast driver"). Individual parameters in the system can be modified based on this

classification. In the system according to Figure 19, the device 5-19 is able to influence, for example, the gradient limitation 5-11, the feed-forward filter 5-18 or the function generator 5-15.

A nominal speed that, for example, is predetermined by the function generator 5-15 can be limited to certain absolute values, e.g., -1.0 m/s^2, +1.5 m/s^2. If the driver briefly exceeds the speed set by the cruise control by actuating the gas pedal, e.g., when passing a truck, the controller is switched to standby due to the driver's intervention. After this speed is exceeded, i.e., after the process of passing the truck is completed, the motor vehicle decelerates to the speed set by the cruise control. In order to prevent this deceleration from becoming excessively fast, e.g., to prevent the truck which was just passed from needing to decelerate, the limitation of the acceleration predetermined by the function generator 5-15 can be reduced, e.g., to -0.7 m/s^2, +1.0 m/s^2. Such changes of limitations can generally be carried out after interventions by the driver. If the required acceleration lies below the set limiting value, the original, higher limiting values can be readjusted.

The above-mentioned functions can be implemented with discrete components or devices. However, it would also be conceivable to use an appropriately programmed computer that receives digital input signals and processes these signals in discrete-time fashion.

Another aspect of the invention pertains to a method for "smoothly" actuating a hydraulic brake in accordance with the "sliding mode" principle as well as a device for carrying out this method.

It is generally known that a nearly arbitrary pressure which is only limited by the pressure generator (pump) or the pressure reservoir can be built up in a recipient (e.g., a brake cylinder) with at least one digitally switched valve and a pressure generator (preferably a pump) or a pressure reservoir. This is realized due to the fact that the pressure build-up at a constant inlet pressure takes place in opposition to a leakage rate that can be adjusted by the digital valve, or that a connection (a valve) between the recipient (e.g., the brake cylinder) and the pressure generator or pressure reservoir is temporarily produced at a constant leakage rate. In this case, valves that are open in the deenergized state (SO) and valves that are closed in the deenergized state (SG) are used as the digital valves.

Systems of this type have the disadvantage that the valves are generally switched in pulse-width modulated fashion. However, this requires a high computation capacity for calculating the pulse widths (on and/or off).

The objective of this aspect of the invention consists of disclosing a method and a device which make it possible to reduce the required processor power to a minimum.

[This objective is attained with the characteristics of Claims 89 and 96. The respective subordinate claims pertain to preferred embodiments of the method and the device.]

The method is characterized by outputting a pressure build-up signal and a pressure reduction signal to the means for adjusting the brake pressure so as to attain a nominal brake pressure p_{nom}. In this case, the means for adjusting the brake pressure consists of two digitally switched valves in one embodiment. These valves are respectively connected to the pressure generator or the pressure reservoir, the pressureless reservoir and the brake cylinder (recipient). One valve connects the pressure reservoir to the brake cylinder, and the second valve connects the pressureless reservoir to the brake cylinder. The desired pressure in the consumer (recipient) is adjusted by means of a correspondingly timed opening and closing of the digitally switched valves. Another embodiment is, in particular, characterized by the fact that the first valve can be eliminated if one takes into consideration the finite volumetric flow from the pressure generator through the supply lines. In this case, the pressure reduction realized with the second valve (directly in front of the pressureless reservoir) only need occur for a brief period of time.

In one preferred embodiment of the method, a nominal volumetric flow Q_{nom} is determined from the nominal brake pressure p_{nom} and an actual pressure p_{act} on a brake cylinder which corresponds to a measured pressure p_{meas} on the valves. In this case, the pressure regulator calculates a volumetric flow of the fluid which is required for adjusting the nominal pressure p_{nom} by comparing the actual pressure p_{act} with a predetermined pressure, i.e., the nominal pressure p_{nom}. Here, the actual pressure p_{act} in the brake cylinder is determined by a pressure monitor from the pressure p_{meas} measured at the valves.

The model on which the pressure monitor is based also takes into consideration the impedance of the supply lines which acts upon the fluid in addition to the pressure difference between the measuring point and the brake. The impedance and the pressure difference determine the volumetric flow through the supply lines, i.e., the volume flowing through the supply lines per unit time. Here, the volumetric flow may, in particular, be directly proportional to the impedance and the square root of the pressure difference between the measuring point and the brake. If the volume that has entered the brake cylinder over a certain time is known, the brake pressure is also known. In this case, the brake pressure depends, for example, on the square of the volume of the brake cylinder.

This means that the volumetric flow to be adjusted is determined, and the brake control can be realized in such a way that opening or closing signals are fed to the pressure build-up valve and the pressure reduction valve in rapid succession.

In a linearized embodiment, the square root dependence of the volumetric flow on the pressure difference is replaced by a linear dependence, where the operating point of the control circuit must be chosen such that no excessively large deviations occur in either direction. Naturally, this is only possible over a limited range.

In an additional refinement of this embodiment, the signals for controlling the volumetric flow may also be filtered before they are fed to the valves. This takes place in a separate control circuit that is quasi series-connected to the aforementioned circuit. Here, the instantaneous volumetric flow is fed back to the nominal volumetric flow. Actuating signals for the digital valve(s) are generated in accordance with the so-called sliding mode control principle from the nominal volumetric flow and the actual volumetric flow. The pressure build-up signal as well as the pressure reduction signal consequently are determined from the nominal volumetric flow and an actual volumetric flow that corresponds to the measured pressure.

In one preferred embodiment, the time derivative of the actual volumetric flow may also be taken into consideration in addition to the actual volumetric flow.

In order to prevent short-circuits between the pressure reservoir and the leak, both valves in an embodiment with two digital valves cannot be simultaneously opened. Consequently, the pressure build-up signal and the pressure reduction signal are generated complementarily to one another so that their switch-on times do not coincide, i.e., one valve can be only opened if the other valve is closed.

In the method according to the invention, the inertia of the fluid or the valve is utilized. In other words, the pressure is no longer controlled, but the control is exclusively realized by regulating the volumetric flow of the fluid.

One general advantage of the method according to the invention is that the pressure control may take place relatively slowly. This means that it can be carried out by a conventional processor that also must fulfill other functions and consequently need not be particularly fast. The control of the volumetric flow takes place rapidly by means of a application-specific control circuit that is preferably realized in the form of an analog or a fast digital circuit. Since the pressure control and the volumetric flow control are separated, a more highly dynamic control is possible. The control

is also not dependent on the cycle times of the processor system and may take place at a rate of up to a few kHz.

[One embodiment of the method according to the invention is described below with reference to the figures, where:

Figure 23 shows the general design of the pressure control according to the invention in the form of a block diagram,

Figure 24 shows an embodiment of a pressure monitor with a simple pressure controller,

Figure 25 shows the nonlinear monitor of a brake system,

Figures 26a and 26b respectively show the control circuit which corresponds to the nonlinear monitor in Figure 25 and the linearized control circuit,

Figure 27 shows a block diagram of one embodiment of the combined control circuit,

Figure 28 shows a brake circuit, in which the system according to the invention is utilized, and

Figure 29 shows a brake circuit that contains only one digital valve instead of the previously described two digital valves.]

Figure 23 shows two series-connected control circuits: one for pressure control and one for volumetric flow control. The second control circuit is optional and will be described further below.

A nominal pressure p_{nom} for the brake system is input into the first control circuit. This first control circuit contains a subtractor 6-1, a pressure controller 6-2 and a pressure monitor 6-3. In this case, the pressure monitor 6-3 determines an actual pressure p_{act} which is subtracted from the nominal pressure p_{nom} at the input of the control circuit based on a measured pressure p_{meas} in the hydraulic system 6-6, where the difference is then additionally processed by the pressure controller. In this embodiment of the invention, the pressure controller also forwards other conditions which serve for adjusting the model of the pressure observation to the pressure monitor. The output variable of the pressure controller is a signal that corresponds to the volumetric flow Q_{nom} which must be generated in order to reach the required brake pressure. This signal Q_{nom} is converted into control signals for one or more (not-shown) digital valves 6-7 and 6-8 in the hydraulic system 6-6 by a volumetric flow controller 6-4. The sequence and the generation of these signals is described below with reference to Figure 26a and Figure 27.

The pressure monitor 6-3 determines the actual pressure p_{act} based on the pressure p_{meas} measured in the hydraulic system 6-6. However, the pressure monitor may also consist of a control circuit. In the preferred embodiment shown in Figure 24, the control circuit output variable p_{act} is

determined from the input variable p_{meas} by means of negative feedback. For this purpose, a variable p_{act} is subtracted from the measured pressure p_{meas} at subtractor 6-9, analogously to the design of the first control circuit shown in Figure 23. The difference between these two signals is converted into an actual pressure p_{act} by a first multiplication element 6-10, a first integration element 6-11 and a first characteristic element 6--2. This can be based on several independent models; the model of the control circuit of this embodiment is based on the image shown in Figure 25. The output variable may consist of a value that corresponds to a pressure as well as a value that corresponds to volumetric flow.

In order to keep the measuring paths relatively short and minimize interference on the transmission path, the pressure of a (sub-)system is preferably measured in the immediate vicinity of the central control units. However, this has the disadvantage that changes in the pressure due to influences caused by the pressure line are not detected. This can be solved with a model that takes into consideration known influences of the pressure lines and determines the variables actually present at the line end from the values measured at a central location. The control elements 6-9 to 6-12 are based on such a model, where said model is shown in Figure 25. In this figure, the characteristics of the supply line 6-13 for the fluid are combined into an impedance D_v 6-14. The supply lines end at the brake 6-15 in a (not-shown) brake cylinder that has volume V. The volumetric flow Q flowing through the supply lines 6-13 is proportional to the impedance and to the square root of the differential pressure in the supply line 6-13 in this model This means that while taking into consideration the direction of the volumetric flow the volumetric flow can be expressed in the form of

$$Q = D_v * \text{sign}\ (p_{meas} - p_{act)} * (|p_{meas} - p_{act}|)^{1/2} \qquad (6/1)$$

Sign (p_{meas} - p_{act}) represents the flow direction, and $|p_{meas} - p_{act}|$ represents the absolute value of the differential pressure.

The pressure is measured directly behind a (not-shown) valve for controlling the volumetric flow by means of a pressure sensor 6-16 and forwarded to the pressure monitor 6-3. The brake pressure or the actual pressure on the brakes p_{act} can be estimated from the prior or current volumetric flow Q_{act} to the brake cylinders. This embodiment is based on a quadratic relation, so that the brake pressure p_{act} can be illustrated in the form of

$$P_{act} = A * V + B * V^2 \qquad (6/2)$$

The change in the volume of the brake cylinder V then results from the relation

$$V = \int Q\, dt \qquad (6/3)$$

The pressure monitor determines the instantaneous brake pressure from these three dependencies, wherein said instantaneous brake pressure is then subtracted from the input value p_{nom} at the input of the first control circuit in Figure 23.

The pressure controller 6-2 needs merely consist of a simple characteristic element as shown in Figure 24. This characteristic element outputs a volumetric flow that, as described above, is converted into signals for digital valves 6-7 and 6-8 by a volumetric flow controller 6-4 depending on the respective input.

In a somewhat simplified version of the first control circuit shown in Figure 23, a "linearized" pressure monitor is used. Such a linearized pressure monitor is shown in Figure 26b. Figure 26a shows a nonlinear pressure monitor as is used in the embodiment according to Figure 24. In this case, the design shown in Figure 26a is essentially identical to that shown in Figure 24 which contains the same elements, namely a subtractor 6-9, a multiplier 6-10, an integrator 6-11 and a characteristic element 6-12. In contrast to the previously described embodiment, the output variable consists, however, of a volumetric flow Q instead of the brake pressure p_{act}. In the linearized pressure monitor shown in Figure 26b, the multiplier 6-10 is replaced with a first proportional element 6-17, and the characteristic element 6-12 is replaced with a second proportional element 6-18. This simplifies the design of the pressure monitor and, among other things, allows faster switching processes. However, the function of the pressure monitor 6-3 is identical in both instances.

The function of the volumetric flow controller is described below with reference to Figures 23 and 27.

As described above, the output signal of the first control circuit shown in Figure 23 which contains a pressure controller 6-1 and a pressure monitor 6- can be directly converted into control signals for the digital valves 6-7 and 6-8 by a volume controller 6-4. However, in order to achieve an even more superior control in actuating the digital valves, a volumetric flow monitor 6-5 is used.

The control circuit that adjusts the volumetric flow Q_{nom} is designed in the form of a negative feedback circuit. The input variable of this negative feedback circuit forms the output variable of the first control circuit (the output variable consequently must consist of a volumetric flow signal). A value Q_{act} that was generated by the volumetric flow monitor 6-5 is subtracted from the output signal of the first control circuit Q_{nom}. The volumetric flow monitor has determined this value based on the measured pressure P_{meas} that already served as the variable input into the actual pressure p_{act} by the pressure monitor. The general design of this second control circuit for adjusting the switching signals for the digital valves 6-7 and 6-8 in the hydraulic system 6-6 is obvious to a person skilled in the art and is consequently not discussed in greater detail.

Figure 27 shows that the volumetric flow monitor 6-5 may simply consist of a first DT_1-element. The output signal of this element then corresponds to the actual volumetric flow Q_{act} which is subtracted from the nominal volumetric flow Q_{nom} output by the first control circuit shown in Figure 23 at the input of the control loop. This is shown in the right-hand portion of Figure 27. The signal Q_{act} is present at inverting inputs of the two subtractors 6-19 and 6-20. However, this signal is also present at the inputs of a second and a third DT_1-element, the outputs of which are inverted and interconnected with the output of one of the subtractors 6-19 and 6-20, so that a composite signal s results. This composite signal s is input at characteristic elements 6-23 and 6-24. The characteristic element 6-23 and 6-24 output a valve actuating signal SO and SG, respectively, for the two digital valves 6-7 and 6-8, respectively, which cause the valves to open and close depending on the input variable. In order to prevent a hydrodynamic or pneumatic short-circuit, the characteristics in the characteristic elements are chosen such that the digital valves 6-7 and 6-8 cannot be open simultaneously. This means that the zero crossing of both characteristics in the characteristic elements 6-23 and 6-24 takes place at different levels of the signal s, and that the switching behavior of the valves which is very similar to a hysteresis curve results over the entire range through which the signal s can pass.

This means that the "sliding mode" control process in this embodiment with a high-pressure hydraulic system takes place as described below. The variable Q_{nom} increases and consequently causes a control error in the volumetric flow controller 6-4. This deviation is converted into a switch-on pulse for the digital valve 6-7, a so-called SG valve, such that the current in the coil of the valve increases. After overcoming the resetting and the frictional forces, the valve begins to open and the pressure measured at the valve 6-7 increases. This also causes the instantaneous volumetric flow Q_{act} to increase. If the control condition is fulfilled, i.e., if the signal s in Figure 27

returns to zero, the valve is switched off and the current drops. The valve then stops the opening motion, and the value Q_{act} drops further or increases very slowly. If the change of Q_{act} always somewhat conforms with the change of Q_{nom} (≈0), the valve 6-7 is switched with a very high frequency, and the valve moves in accordance with the progression of Q_{nom}. The previously described "sliding mode" control process can be most easily realized in the form of an operating relationship that can be illustrated in the form of the condition

$$S = (Q_{nom} - Q_{act}) - (dQ_{act}/dt) * K \qquad (6/4)$$

Here, control signals s, which represent the input signals of the characteristic elements 6-23 and 6-24 in Figure 27, are output at a very high frequency if the first term becomes equal to 0, i.e., disappears. However, if $s > 0$, the valves 6-7 and 6-8 must be switched in such a way that a pressure build-up takes place. If $s < 0$, the valves 6-7 and 6-8 must cause a pressure reduction. A certain idle time in the valve control between the output of an SO actuating signal and an SG actuating signal ensures--as described above--that both valves cannot be simultaneously actuated. However, both valves may also be briefly opened in order to minimize ripple during the pressure build-up in the recipient.

The design of the pressure system, in which the pressure control according to the invention is utilized, is shown in Figure 28. Pressure is built up by means of a pressure generator 6-25. The pressure generator usually consists of a pump with a motor that serves as the drive. The pressure circuit is aligned in one direction by means of return valves 6-26 and 6-7 which are arranged upstream and downstream of the pressure generator 6-25. The SG valve 6-7 located downstream to the pressure generator 6-25 and the first return valve 6-27. If pressure must be built up downstream to this valve 6-7, i.e., if the condition $s > 0$ is fulfilled, this valve is actuated by the characteristic element 6-24 such that the valve opens. The pressure is measured directly behind the valve 6-7 by the pressure sensor 6-16. If the pressure behind the valve increases above a predetermined value, the control condition changes to $s = 0$ or $s < 0$, i.e., the SG valve 6-7 is first closed and the SO valve 6-8 is then opened. Due to this measure, the pressure on the brakes 6-15 can be discharged, and the fluid flows into the reservoir 6-28. This alternate switching-on of the valves in connection with the monitoring by the pressure sensor 6-16 in the immediate vicinity of the valves 6-7 and 6-8 to be actuated allows a very fine metering of the brake pressure as described above.

In another embodiment of this brake system, one valve can be eliminated. This embodiment is shown in Figure 29. In this case, the pressure generator 6-25 constantly operates in opposition to the pressure in the brake system, where the SO valve 6-7 periodically opens such that the pressure cannot exceed a predetermined value. In other respects, the function of this embodiment is identical to that of the embodiment described above. Analogously, the pressure generator may also be actuated identically to the SG valve.

The pressure system can be used for arbitrary brake systems and brake systems that are arbitrarily divided over the wheels of a motor vehicle.

Another aspect of the invention pertains to a method and a device for achieving a transition between two driving conditions with the fewest possible jerks.

A method and a device for stopping an object with few jerks is known from DE 34 34 793. In this method according to the state of the art, the instantaneous speed and the instantaneous deceleration of an object equipped with a controllable brake system is determined. A nominal deceleration value is calculated from these two values. The nominal deceleration value is compared with the instantaneous deceleration and a corresponding differential signal is generated. The brake system is actuated in such a way that the differential signal becomes minimal and the instantaneous deceleration is adjusted to the nominal deceleration value. If "stopping with few jerks" is desired, a calculated nominal deceleration value is output, where the deceleration is proportional to a function of the speed. In this case, the instantaneous deceleration and the nominal deceleration value are identical at the beginning of the operating mode "stopping with few jerks." The nominal deceleration value is approximately zero when the instantaneous speed approaches zero.

In the method according to the state of the art, a beginning condition and an end condition are defined by the speed value and deceleration value, respectively. In the driver assistance systems which are currently in development and intended for assisting the driver in accelerating and decelerating the motor vehicle, a limitation to acceleration and speed represents a disadvantage that clearly limits the scope of utilization of the system. More flexible solutions are, in particular, desirable for automatic controls of the driving speed (cruise control), the distance to the vehicle ahead, the process of starting from a stop and--as the only aspect taken into consideration in the cited state of the art--the targeted deceleration. In all these instances, an automatic transition from a given instantaneous driving condition to a desired future driving condition should take place.

Consequently, the objective of this aspect of the invention consists of realizing the transition from one driving condition to a desired driving condition, where this should be possible for all driving condition parameters, and wherein the jerk associated with the transition should be minimal.

[This objective is attained with the characteristics of Claims 105 and 112. The respective subordinate claims pertain to preferred embodiments of this object of the invention.]

The solution of the above-mentioned problem is based on the calculation of the transition acceleration by means of a calculus of variations. The result of the calculus of variations is an algorithm that delivers the optimal time characteristic of the driving condition in the above-mentioned sense during the transition phase. In this case, the duration of the transition phase may be a predetermined, constant value or represent a function of at least one of the above-mentioned driving parameters.

In the method according to the invention, the actual condition is defined by the instantaneous location, the instantaneous absolute speed, the instantaneous acceleration as well as the instantaneous driving parameters that define the driving condition in an additional reference system. This pertains, in particular, to the vehicle that drives ahead. This means that the corresponding parameters are the distance (to the vehicle driving ahead) the relative speed (i.e., with respect to the vehicle driving ahead) and the relative acceleration (between the first and second vehicles). For example, if the instantaneous driving situation is characterized by the fact that the distance is excessively short for ensuring safe driving conditions, i.e., the distance differs from the nominal distance, a nominal longitudinal acceleration progression that causes a transition from the instantaneous driving condition with the unsuitable distance into a nominal driving condition with the desired distance with few jerks is determined with the method according to the invention. For this purpose, a time-dependent acceleration function that is defined over a predetermined time interval is determined in such a way that its integral as a function of the square of its time derivative is a minimum, where the beginning condition and the end condition are defined. In the above-mentioned example, this would, in particular, pertain to information regarding the instantaneous distance to the vehicle driving ahead and the definition of a nominal distance to the vehicle driving ahead. This can be mathematically expressed in the form of

$$\int (x\ (t))^2 dt = \text{minimal} \qquad 7/1$$

with

$$\bar{v}\ (t = o) = \bar{v}_a; \qquad \bar{v}\ (t = t_e) = \bar{v}_e; \qquad 7/2$$

wherein $\bar{v}$ is a so-called six-vector that can be illustrated in the form of

$$\bar{v} = x$$

$$\bar{v} = \dot{x}$$

$$\bar{v} = \ddot{x}$$

$$\bar{v} = s$$

$$\bar{v} = \dot{s}$$

$$\bar{v} = \ddot{s}$$

In a preferred embodiment of the method according to the invention, the acceleration function which fulfills the above-mentioned minimal condition is selected from a set of predetermined functions such that the storage area is somewhat limited. This is particularly advantageous in the numerical evaluation of favorable acceleration functions because the functions to be searched must be stored in a limited memory. Depending on the problem on which the calculus of variations is based, the quantity of the functions to be searched may, for example, be limited to functions that are dependent on the square of the time. Since a quadratic dependence may, under certain circumstances, not lead to the desired result, it may be necessary also to take into consideration functions that depend on the cube of the time. In both instances, the stored functions may depend on the predetermined transition time for reaching the nominal condition and/or on the nominal distance and/or on the actual condition and/or the nominal condition based on the parameters. In addition, the transition time itself may also depend on driving parameters.

The evaluation of the most favorable acceleration function as the nominal longitudinal acceleration is described below with reference to one example that is illustrated in the figure. The figure shows a flow chart, according to which the method is carried out.

In the example described below, the observed vehicle, into which a device for carrying out the method for controlling the longitudinal motor vehicle movement according to the invention is installed, travels over range x(t) in the time t. In this case, the separation s(t) between vehicles is continuously measured. This is realized with conventional distance sensors, e.g., radar sensors, ultrasonic sensors or laser sensors. The distance measurement itself may also be realized with a series of pulses that are continuously emitted by the sensor and received by a detector that is interconnected to the sensor. However, it is also possible to use continuous signals. These continuous signals are particularly advantageous if the changes should also be measured in continuous fashion. In pulsed mode, this is only possible by measuring the transit time differences

from pulse to pulse, i.e., in discrete fashion. When using a continuous signal, the frequency shift of the signal caused by the relative speed can be used. The absolute value of the distance can only be determined by means of triangulation or the like when using a continuous signal. The nominal separation between vehicles is defined by

$$\underline{S}_{nom}[s_{soll}]\,(\dot{x}) = b_o + b_1\dot{x} + b_2\dot{x}^2$$

[Key: 1 S_{nom}] 7/3

wherein $\dot{x}$ represents the driving speed and b_0, b_1 and b_2 represent parameters that are discussed further below. In this particular embodiment, it is assumed that the nominal separation differs from the instantaneous separation between vehicles. The instantaneous driving condition, i.e., the driving condition at time t = 0, can be illustrated in the form of a six-vector as shown below:

$$\begin{aligned} x\ (o) &= x_o \\ \dot{x}\ (o) &= \dot{x}_o \\ \ddot{x}\ (o) &= \ddot{x}_o \\ s\ (o) &= s_o \\ \dot{s}\ (o) &= \dot{s}_o \\ \ddot{s}\ (o) &= \ddot{s}_o \end{aligned}$$

In order to reach the nominal distance, the driving condition defined by the six-vector<u>s</u> must change to a driving condition that is defined by the following six-vector<u>s</u>:

$$\begin{aligned} x\ (t_e) &= x_e \\ \dot{x}\ (t_e) &= \dot{x}_e \\ \ddot{x}\ (t_e) &= \ddot{x}_e \\ s\ (t_e) &= \underline{s}_{nom}\,[s_{soll]} \qquad (\dot{x})\,(t) \\ \dot{s}\ (t_e) &= o \\ \ddot{s} &= t_e) \end{aligned}$$

[Key: 1 S_{nom}]

This transition must take place in such a way that the integral in equation 90/1 becomes minimal. This means that the square of the jerk is minimized. Due to the squaring of the function to be integrated, the objective has become independent of whether the transition acceleration is positive or negative. This means that if a solution to this problem is found with the boundary condition defined by the previously discussed six-vector, the problem is solved when decelerating and when accelerating the motor vehicle. However, it also must be observed that the limits of integration for the calculation of the integral are defined. It is, however, possible to constantly adapt these limits of integration to the instantaneous driving condition. In other words, the transition time t may be freely selected.

When carrying out the calculation, one initially encounters the problem that it is not known at the time $t = 0$ how the vehicle driving ahead moves for $t > 0$. Consequently, its movement must be extrapolated. For this purpose, the movement is developed into a Taylor series which is terminated after the second order term, so that the following results for the movement $x(t) + s(t)$:

$$X(t) + s(t) = (x_o + s_o) + (\dot{x}_o + \dot{s}_o)t + 1/2\,(\ddot{x}_o + \ddot{s}_o)\,t^2 \qquad 7/4$$

If this equation is differentiated several times with respect to time, equation 7/4 is transformed into equation

$$\dddot{x}(t) = -\dddot{s}(t) \qquad 7/5$$

such that the variation objective can be formulated in the form of

$$\int_o (\dddot{s}(t))^2\,dt \rightarrow \mathrm{Min} \qquad 7/6$$

In this case, the following boundary conditions apply

$$s(o) = x_o$$
$$\dot{s}(o) = \dot{s}_o$$
$$\ddot{s}(o) = \ddot{s}_o$$

$$x\,(t_e) = b_o + b_1\,\dot{x}\,(t_e) + b_2(\dot{x}\,(t_e))^2$$
$$\dot{x}\,(t_e) = 0 \qquad 7/7$$
$$\ddot{x}\,(t_e) = 0$$

where, in the term for $x\,(t_e)$ the value for $\dot{x}\,(t_e)$ can be substituted. The intermediate result for the time history of the separation between vehicles results in the form of

$$\begin{aligned}
s(t) = {} & s_o + \dot{s}_o\,t + (\ddot{s}_o t^2)/2 + \\
& (t^4\,(30\,s_o + 16\,\dot{s}_o\,t_e + 3\,\ddot{s}_o t_e^{\,2})/2 - \\
& \quad 30\,(b_o + b_1(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \qquad b_2\,(\dot{s}_o + \ddot{s}_o t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))/2\ t_e^{\,4}) + \\
& (t^5\,(-12\,s_o - 6\,\dot{s}_o t_e - \ddot{s}_o\,t_e^{\,2} + \\
& \quad 12\,(b_o + b_1(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \qquad b_2\,(\dot{s}_o + \ddot{s}_o t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))(/2\ t_e^{\,5}) + \\
& (t^3\,(-20\,s_o - 12\,\dot{s}_o t_e - 3\,\ddot{s}_o\,t_e^{\,2} + \\
& \quad 20\,(b_o + b_1(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \qquad b_2\,(\dot{s}_o + \ddot{s}_o t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))/2\ t_e^{\,3}). \qquad 7/8
\end{aligned}$$

Consequently, the following results for the optimal acceleration progression for the absolute acceleration $\ddot{x}$

$$\begin{aligned}
\ddot{x}\,(t) = {} & \ddot{x}_o - (6\,t^2\,(30 s_o + 16\,\dot{s}_o t_e + 3\,\ddot{s}_o\,te^2 - \\
& 30\,(b_o + b_1\,(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \quad b_2\,(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))/\,t_e^{\,4}) \\
& (10\,t^3\,(-12\,s_o - 6\,\dot{s}_o t_e - \ddot{s}_o\,t_e^{\,2} + \\
& \quad 12\,(b_o + b_1(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \qquad b_2\,(\dot{s}_o + \ddot{s}_o t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))/\,t_e^{\,5} - \\
& (3\,t\,(-20\,s_o - 12\,\dot{s}_o t_e - 3\,\ddot{s}_o\,t_e^{\,2} + \\
& \quad 20\,(b_o + b_1(\dot{s}_o + \ddot{s}_o\,t_e + t_e\,\ddot{x}_o + \dot{x}_o) + \\
& \qquad b_2\,(\dot{s}_o + \ddot{s}_o t_e + t_e\,\ddot{x}_o + \dot{x}_o)^2)))/\,t_e^{\,3} \qquad 7/9
\end{aligned}$$

As described previously, this is how one proceeds when determining the optimal acceleration function, if a transition from an initial condition with a predetermined separation, a predetermined relative speed, and a predetermined relative acceleration, as well as a predetermined speed and a predetermined acceleration of the motor vehicle into an end condition with a predetermined nominal separation from the vehicle driving ahead should be achieved. However, this represents a special problem, the mathematical solution of which was presented as an example. It would also be possible to adjust other transition conditions, e.g., the transition from an instantaneous speed into a nominal speed or nominal relative speed and a transition between an instantaneous acceleration and a nominal relative acceleration or nominal acceleration, the calculation of which takes place in accordance with essentially the same principles as described above.

The method, according to the invention, which is identical for all transition conditions is shown in Figure 30. If an optimum acceleration function for the transition from an actual condition into a nominal condition should be determined, the method is started (step 7-S1) by writing a high value into memory. This value in the memory represents the integral of a fictitious function--in step 7-S1--which must be minimized, wherein selected functions are compared with this fictitious function in the ensuing steps.

In the next step 7-S2, a function that is subsequently processed and compared with the above-mentioned fictitious function is selected from a function space. In the simplest case, the memory contains a series of first-order polynomials, where the desired function is, depending on the desired highest power of the function, formed by multiplying several polynominals of the first degree. In addition, the memory may also contain exponential functions in the form of its decay coefficients. A person skilled in the art is familiar with these techniques, which are thus not discussed in detail.

During each selection of a function from the function space, a loop parameter n is simultaneously incremented.

In the next step 7-S3, the selected function is differentiated with respect to time and then squared.

In step 7-S4, the function is finally integrated over the limits 0 and t_e, i.e., the end of the transition phase. Here, t_e initially represents a fixed value. However, this value may, depending on the respective requirements, be adapted to the respective nominal speed and/or the respective nominal separation and/or the absolute speed and/or the instantaneous separation during the course of the method.

In step 7-S5, the value of this integral is compared with the value stored in memory in step S1. If the value of the integral less than the value stored in memory, the process continues with step 7-S7, where the function is stored in a function memory in parameterized form. This function memory is designed similarly to the function space in step 7-S2, but this memory is designed for only one function. After step 7-S7, it is determined whether the loop parameter is identical to a predetermined value which represents the upper limit of the functions to be tested. This comparison takes place in step S6.

If it is determined in step 7-S5 that the value stored in the memory is less than the integral value when comparing the previously evaluated integral with the value stored in the memory, the process also continues directly with step 7-S6, i.e., step 7-S7 is bypassed.

If it is determined in step 7-S6 that the loop parameter n has not yet reached the maximum value n_{max}, the process returns to step 7-S2, and a new function is selected from the function space while incrementing the loop parameter n. However, if it is determined that the loop parameter n is already identical to the maximum value n_{max}, the function stored in the function memory is output in step 7-S8 as the result. The sequence ends with step 7-S9 which follows step 7-S8.

Once a mathematical expression for the optimal acceleration function that, for example, represents a third-order polynomial is obtained after carrying out the method according to the invention, the coefficients of the polynominal depend on the predetermined transition time t_e for reaching the nominal condition and/or on the instantaneous nominal separation and/or on the instantaneous relative speed and/or the instantaneous relative acceleration and/or the instantaneous absolute speed and/or the instantaneous absolute acceleration based on the parameters. In this context, the term "instantaneous" refers to the beginning of the transition phase. When defining such a third-order polynominal as is illustrated in equation 7/9, the independent variable t may be set equal to the sampling time during the digital processing for a discrete-time longitudinal motor vehicle controller, so that the optimal acceleration value for the ensuing sampling time is obtained. If one intends to utilize linear filters for determining the optimal acceleration change in a continuous longitudinal motor vehicle controller, one attains the filter coefficients by developing equation 7/9 into a series up to the desired order.

The device according to the invention for carrying out the above-mentioned method contains a memory for storing a numerical value that represent the integral of a function, several function memories that are combined into a function space, where the functions, from which the transition function should be determined, are previously stored in said function memories, and an individual

function memory in which the function that solves the variation problem is stored. In addition, the device contains a differentiation element for differentiating a selected function, where the output of said differentiation element is connected to the input of a squaring element for squaring the differentiated function. This squaring element multiplies the function by itself and then forwards the result to the input of an integrator. This integrator forms the integral of the input signal, wherein the lower limit of integration generally coincides with the start of the sequence of the process. However, the lower limit of integration may, for example, also be freely selected by the driver, and the upper limit of integration t_e is predetermined by the driver. In addition, the control device according to the invention contains a comparator for comparing the output value of the integrator with the numerical value stored in memory and for outputting the determined optimal acceleration function.

Another aspect of the invention pertains to a distance control method with virtual springs and dampers, i.e., with an artificially generated dynamic during the process of adjusting the separation between vehicles, as well as a device for carrying out this method.

It is generally known to determine the nominal separation from the vehicle driving ahead as a function of the instantaneous speed of the second vehicle. However, the nominal separation between vehicles can also be determined as a function of the relative speed between vehicles. For this purpose, the second vehicle speed and the separation between vehicles is determined. One system of this type is known from DE 43 12 595, for example. The safety system described in this publication contains a distance sensor for determining the separation between vehicles and a program-controlled computer for processing the signals of the distance sensor and outputting corresponding control commands. The ultrasonic distance sensor operates in accordance with the propagation time principle. The computer differentiates the measured value of the distance sensor with respect to time, and activates a warning device and decelerates the motor vehicle if the relative speed is sufficiently high and the separation sufficiently small that a collision is unavoidable without initiating a braking maneuver. Another example of such a safety system is known from US 5 165 497.

In order to control the separation between vehicles, the (second) motor vehicle must be respectively accelerated or decelerated with the aid of the so-called E-Gas, i.e., the electrically controllable engine torque, and an active brake, i.e., an electrically actuated brake, in such a way that a predetermined distance which depends on the speed (of the second motor vehicle) is adjusted.

However, practical tests have demonstrated that a significant period of time may pass between the output of the predetermined acceleration value by the control unit and the time at which the motor vehicle actually reaches the acceleration value. This so-called idle time causes, in the above-mentioned controllers and systems according to the state of the art, the entire system, consisting of several motor vehicles driving one behind another, to oscillate, so that the oscillations keep getting bigger, until finally individual speeds of motor vehicles drop to zero or a traffic jam occurs in a line of motor vehicles.

Consequently, the objective of this aspect of the invention consists of disclosing a method and a device which make it possible to prevent undesirably sudden changes in the speed of the motor vehicle.

This objective is attained with the characteristics of Claims 114 and 118. The respective subordinate claims pertain to preferred embodiments of this method and this device.

While investigating the above-mentioned problem, the inventor recognized that the separation control between two vehicles can be described with a model that consists of a mass coupled to a spring and a damper for the friction. The following description pertains to this model.

The method is characterized by outputting a nominal tracking acceleration for reaching a nominal separation S_{nom} between vehicles, where said nominal separation depends on the instantaneous separation s, the relative speed v_{rel} and the absolute speed v_{abs}. In this context, the term instantaneous separation s refers to the separation at the time at which the output of the nominal tracking acceleration a_{Tnom} takes place. This dependence of the nominal tracking acceleration a_{Tnom} on the separation s, the relative speed v_{rel} and the speed of the second vehicle or absolute speed v_{abs} introduces, in contrast to the state of the art, an additional term into the determination of the nominal tracking speed which, when observed in a model, corresponds to the friction of the vehicle on the roadway. The idle times or reaction times of the controls and actuators of the motor vehicle can be modeled by means of the mass, and the control of a constant separation between vehicles can be modeled by means of a spring.

In one preferred embodiment, the nominal tracking acceleration $a_{F\ nom}$ is the sum of a first component f that depends on the instantaneous separation s from the vehicle driving ahead, and a second component g that depends on the relative speed v_{rel} between vehicles. Here, the dependencies are a function of the absolute speed v_{abs}, i.e., this can be illustrated in the form of the formula

$$a_{F\ nom} = a_{F\ nom}\,(f(v_{abs}, s)\ ,\ g(v_{absl}, v_{rel}))\qquad 8/1$$

where f and g are predetermined functions.

In one particularly preferred embodiment, the functions f and g are added.

In another preferred embodiment of this method, the nominal tracking acceleration $a_{F\ nom}$ is determined in the form of a sum of three components. Here, the first term of the sum or the first components is a term that depends on the separation s. This separation-dependent term may, in particular, be proportional to the second derivative of separation with respect to time, wherein said term may also depend directly on the separation. The second term of the sum or the second component depends on the relative speed v_{rel} in this embodiment. The second term of the sum is, in particular, proportional to the relative speed. The third term of the sum depends on the absolute speed, i.e., the speed of the second motor vehicle. The term second motor vehicle refers to the motor vehicle in which the system according to the invention is installed. The third term of the sum is, in particular, proportional to the absolute speed, i.e., a nominal tracking acceleration in the form of

$$a_{Tnom} = a(s) + b * v_{rel} + c * v_{abs}$$

results. Here, a_{Tnom} represents the predetermined acceleration value or the nominal tracking acceleration value, a(s) represents a separation-dependent term, and, in particular, is proportional to the second time derivative of the separation s between the (second) motor vehicle and the vehicle driving ahead, and v_{rel} and v_{abs} respectively represent the relative and absolute speed of the (second) motor vehicle to the vehicle driving ahead and to the road, respectively. The coefficients b and c are weighting factors.

The weighting factors may be constant. However, this has the disadvantage that the additional friction terms ultimately cause the separation between vehicles to undesirably increase. In one preferred embodiment of the method according to the invention, variable coefficients are used in the evaluation of the nominal tracking acceleration. These variable coefficients then preferably depend on the relative speed v_{rel}, so that the following applies:

$$b = b\,(v_{rel})\ ,\ c = c\,(v_{rel})$$

where equation (8/2) can be illustrated as shown below:

$$a_{Trom} = a(s) + b(v_{rel}) * V_{rel} + c(v_{rel}) * v_{abs}$$

The functional dependency of the coefficients on the relative speed is suitably predetermined and adapted to the respective situation. This is, in particular, advantageous if the weighting of the individual components or term of the sums in the above-mentioned equation (8/2) should depend on the driving conditions. This makes it possible for the "damper" between the two vehicles to become the determining factor for the nominal tracking acceleration at low differential speeds and the "damper" between the vehicle and the road to become the determining factor for the nominal tracking acceleration at high differential speeds. The transition between these two cases can be realized smoothly if the dependence of the coefficients on relative speed is also chosen in dependence on time.

Due to the variable coefficients, the correlation between nominal tracking acceleration and relative or absolute speed is no longer linear. This already applies to the very simple equation (8/2). In addition to representing the nominal tracking acceleration as a sum, it is, of course, also possible to find more complicated functions that are based on other friction laws in order to obtain special effects. This essentially corresponds to nonlinear springs and dampers.

The method was numerically simulated and provided the expected result: the oscillations in a line of motor vehicles caused by the idle times between the output of a nominal acceleration value that was calculated without virtual springs and masses and the time at which the desired acceleration is reached were suppressed with the method according to the invention, so that permanent deviations no longer occurred.

[One embodiment of the method according to the invention is described below with reference to the figures, where:

Figure 31 shows the driving situation on which the method according to the invention is based, in terms of a model,

Figure 32 shows an embodiment of the control method according to the invention,

Figure 33 shows another embodiment of the control method according to the invention, and

Figures 34a-34c show the progression of the most important driving variables during the control method according to the invention.]

Figure 31 shows two vehicles 8-1 and 8-2, one behind the other, where the control system according to the invention is installed in the second vehicle 8-1. The two vehicles are connected by means of a virtual spring 8-3 and a virtual damper 8-4. These two virtual coupling elements are adjustable, i.e., a desired or nominal separation between the two motor vehicles results. This desired or nominal separation is composed of a term that depends on the absolute speed and a so-called "offset" term S_{offset}. The term that depends on the absolute speed can be illustrated as the product of a time constant and the absolute speed v_{abs}. The time constant in the product represents the time that would elapse at the instantaneous absolute speed until the (second) motor vehicle 8-1 would impact the stationary "lead" vehicle (time to collision, T_{col}). The damper 8-4 somewhat counteracts the spring and thus prevents excessively high excursion or oscillation amplitudes of the system consisting of two vehicles, one behind the other.

The circumstances shown in Figure 31 correctly reflect the situation in the steady-state case. However, during the transition to the temporally changed case, the development of the driving parameters over time must also be taken into consideration. The design of the control system according to the invention which is used for this purpose is shown in Figure 32.

A distance sensor 8-5 outputs signals that correspond to the instantaneous separation of the vehicle 8-1 from the vehicle 8-2 driving ahead. These signals may be derived from the transit time of, for example, ultrasonic pulses or output signals of infrared sensors, radar sensors, and the like. However, these signals may also be obtained by means of triangulation when using continuous wave signals. Due to the continuously measured distance, its change over time, i.e., its time derivative v_{rel}, is also known. The speed selector switch simultaneously predetermines the instantaneous nominal speed of vehicle 8-1 and consequently a nominal separation that vehicle 8-1 must maintain relative to the vehicle 8-2. As described previously with reference to Figure 31, this nominal separation can be described in the form of

$$S_{nom} = T_{col} * V_{abs} + S_{offset}$$

The nominal separation d output by the speed selector switch 8-6 is subtracted from the instantaneous distance output by the distance sensor 8-5 in a subtractor 8-7. The difference signal between both distances which is output by the subtractor 8-7 represents the input variable for a spring characteristic element 8-9. A first acceleration value is generated in this spring characteristic

element 8-9 in accordance with the input variable. The relationship between the input variable and the output variable, and hence the first acceleration value, is usually nonlinear in this case.

In addition to the determination of a first acceleration value by the spring characteristic element 8-9, the distance signal of the distance sensor 8-5 which is differentiated with respect to time (and, in particular, may be obtained from a Doppler shift measurement) is used for determining a second acceleration value. In this case, the temporally derived signal is used as the input variable for a damping characteristic element 8-8 that outputs a second acceleration value. In this case, the relationship between the input variable and the output value is also usually nonlinear.

In both characteristic elements 8-8 and 8-9, characteristics which depend on the absolute speed are used in the method according to the invention, i.e., the characteristics stored in each characteristic element depend on the parameters for the instantaneous absolute speed v_{abs} of the second vehicle.

The two acceleration values are added in an adder 8-10, filtered and limited with respect to their maximum amplitude by a filter 8-11. This filtered and limited acceleration value corresponds to the nominal tracking acceleration.

In another embodiment of the control device according to the invention, which is shown in Figure 33, the characteristic elements 8-8 and 8-9 are combined into a performance map 8-12, so that a corresponding value for the acceleration can be read from a quasi three-dimensional performance map if the separation and the relative speed of the distance sensor 8-5 are used as input variables. In this case, the family of performance maps also depends on the parameters of the instantaneous absolute speed v_{abs} of the vehicle. The embodiment shown in Figure 33 has the advantage that the adder 8-10 can be eliminated. If the values are stored in a table, calculations are no longer necessary.

Figure 34 shows the progression of important driving variables during the control phase. In Figure 34a, the progression of the separation between vehicle 8-1 and vehicle 8-2 is plotted as a function of time. At time $t = 0$, this separation amounts to, for example, 200 m. The nominal separation is assumed to initially amount to 10 m. However, this nominal separation does not have to be constant over time, wherein the nominal separation depends, as described above, essentially on the instantaneous driving situation, in particular, the speed of the vehicle driving ahead, the absolute speed of the second vehicle, etc.

In order to attain a smooth adjustment of both motor vehicles to the nominal separation as shown at the right of the graphic illustration of the temporal progression of the separation and the

nominal separation, the speed shown in Figure 34b must be adjusted. In this case, it is assumed that the first vehicle 8-2 travels at a constant speed of 50 km/h. If vehicle 8-1 is accelerated in order to reduce the distance to the first vehicle [8-1 [sic] 8-2[]], the nominal separation as a function of changes in dependence on the absolute speed as shown in part a of Figure 34. Since the speed is continuously adjusted as a function of the instantaneous distance from the first motor vehicle 8-2, slight fluctuations in the speed curve which are of somewhat "higher frequency" occur. These portions of higher frequency in the speed manifest themselves in the acceleration signal shown in Figure 34c. In this figure, these portions are clearly defined and show the reaction and the adjustment of the nominal tracking acceleration by the system and method according to the invention.

Another aspect of the invention pertains to an operating concept for a separation-regulating cruise control and, in particular, a method for adjusting the nominal separation between vehicles with a distance controller, where the driver is able to modify the adjusted separation. This aspect of the invention also pertains to a device for carrying out this method.

When contemplating an automatic control for the separation between vehicles, the question regarding the correct amount of separation arises. There are certain rules of thumb, e.g., "half the speedometer reading" and the legally prescribed safety distance of "one fourth of the km/h traveled in meters." However, these values are frequently not observed and the safety distance between motor vehicles becomes too small.

In automatic separation controllers, the nominal separation between vehicles is determined as a function of the own instantaneous speed. In order to realize this separation control, the instantaneous distance to the first vehicle and the absolute speed is determined, whereafter a first nominal separation is determined from the instantaneous separation and the absolute speed.

Such a system is known from DE 31 30 873, for example. The separation controller described in this publication can be used in a first vehicle that is engine-driven and contains a power control element that is prestressed into an idle position for the engine, a brake control element, and a signal generator. The signal generator generates first control signals that are proportional to the distance to the leading second vehicle, as well as second control signals that actuate the power control element and the brake control element once the distance between the motor vehicles falls short of a predetermined distance. If the distance falls short of a first value, the first actuator moves the power control element in the direction of the idle position as the distance becomes smaller, against the effect of an increasing spring force. If the distance falls short of a second value that is

smaller than the first value, and if the power control element was moved toward the idle position by a predetermined distance, the second actuator increasingly decelerates the first vehicle as the distance becomes smaller. If the distance falls short of a third value that is smaller than the second value, the signal generator delivers third control signals for initiating a full brake application of the first motor vehicle to the second actuator, wherein the signal generator also delivers third control signals for resetting the power control element into its idle position and for maintaining the power control element in its idle position to a third actuator.

Another example of such a method for controlling the distance between motor vehicles is known from DE 44 37 678. In this method, the distance between vehicles is determined by a measuring unit, this distance is evaluated by a control unit, and a nominal distance that depends on the speed is adjusted as a function of this evaluation.

However, these controls are usually switched off by the driver if the distance controller constantly must intervene with the vehicle control due to the traffic flow. This would lead to an excessively frequent deceleration of the motor vehicle, e.g., because other motor vehicles frequently merge in front of the vehicle equipped with the distance controller. In most distance controllers, the speed control is immediately switched off once the accelerator pedal or the brake pedal is actuated. Once the driver switches off the distance controller, it may occur that vehicles drive excessively close to one another despite the installed distance controller.

This is good reason variable distance controllers are currently being investigated. Additional operating elements for the driver, e.g., a turning knob or a slide switch, for inputting the degree of falling short of the safety distance, are currently subject of experiments for these distance controllers which are still in the development phase. These new operating elements have the disadvantage that they represent "additional" operating elements, the function of which the driver initially must comprehend.

The objective of this aspect of the invention consists of disclosing a method and a device which make it possible for the driver to fall short of the safety distance without having to switch off the distance controller and without requiring additional operating elements.

This objective is attained with the characteristics of Claims 122 and 126. The respective subordinate claims pertain to preferred embodiments of this method and this device.

The method is characterized by outputting a second nominal separation S_{nom} once the accelerator pedal is actuated. Thus, the driver need not switch off the distance controller. According to the invention, the legally permitted separation is maintained while the distance

controller is switched on as long as the accelerator pedal (gas pedal) of the motor vehicle is in its starting position. However, once the driver actuates the accelerator pedal, the nominal separation to be controlled is shortened as a function of the value of the pedal actuation. Consequently, the driver still has full control over the vehicle and remains responsible for falling short of the safety distance. However, the driver is still able to utilize the advantages of the automatic distance control.

In one preferred embodiment, warning signals, the volume of which depends on distance, where the separation between the motor vehicles goes below the nominal separation, are output once the separation is less than the safety distance. These warning signals are output acoustically and/or optically and/or haptically.

Due to the proposed measures, the operation of the distance controller according to the invention is superior to that of the distance controller of the state of the art because it may remain continuously switched on in all driving situations, particularly in heavy traffic. This means that the distance controller need not be deactivated if the driver intends to go below the safety distance, as is the case with the controller of the state of the art. The behavior of the distance controller according to the invention is transparent with respect to the fact that the actuation of the accelerator pedal causes the second vehicle to move closer to the first vehicle despite the fact that the distance controller is switched on, wherein the second vehicle increases the distance to the first vehicle when the accelerator pedal is released. The distance control always remains active and prevents a collision, even at a reduced safety distance.

One embodiment of the method according to the invention is described below with reference to the figures. [Figure 35 shows a flow chart of one embodiment of the method according to the invention.]

In the method for controlling the nominal separation to the vehicle ahead according to Figure 35, the separation s to the vehicle ahead is measured in step 9-S2 which takes place after the start of the method (step 9-S1), and hence, the activation of the distance controller or the control device. This is conventionally realized with the aid of a distance sensor that, for example, is based on the propagation time measurement of ultrasonic pulses, laser pulses, or radar pulses, or the triangulation of continuous wave laser signals.

An absolute speed v_{abs} of the motor vehicle is then determined in step --S3. For this purpose, the reference speed of an ABS system is preferably utilized. However, it would also be possible to evaluate any other signal that represents the speed of the motor vehicle, e.g., the speedometer signal.

A first nominal separation S_{nom} that depends on the absolute speed v_{abs} is determined from the variables known thus far in step 9-S4.

If it is determined in step 9-S5 that the driver intends to accelerate the motor vehicle by actuating the accelerator panel, i.e., if it is determined that the distance between the two motor vehicles would go below the first nominal separation, the system detects the driver's intentions. For this purpose, the angle of the accelerator pedal can be determined.

A new, second nominal separation $S_{nom'}$ is determined and output in step 9-S7, based on the driver's intentions. In this case, the new nominal separation $S_{nom'}$ may depend on the angle , e.g., linearly or via a previously stored characteristic. The second nominal separation is adjusted in step 9-S8.

After the determination of the new nominal separation $S_{nom'}$, the process jumps to the same step as after step 9-S5, at which the process is continued if the driver has not actuated the accelerator pedal.

The method ultimately examines in step 9-S9 whether the distance control should be switched off. If this is the case, the process jumps to step 9-S10 which represents the end of the process.

If it is not intended to switch off the distance control, the process jumps back to Step 9-S2 and continues with the determination of the instantaneous separation s to the motor vehicle ahead. The previously described steps follow until the motor vehicle has reached its destination or the distance controller is deactivated.

Another aspect of the invention pertains to a method for adapting the curve speed of a motor vehicle while driving through a curve as well as a device for carrying out this method.

It is generally known to automatically adapt the speeds to the instantaneous circumstances and thus assist the driver in controlling the vehicle; consequently, the driver is relieved from having to carry out routinely required operations. On a straight roadway, these tasks are, for example, fulfilled by a distance controller or a cruise control. These components automatically initiate acceleration and deceleration maneuvers as a function of the instantaneous traffic conditions, and thus prevent tailgating or maintain an adjusted cruise control speed independently of hills.

The tasks to be fulfilled by a comprehensive speed control also include the reducing of the speed through a curve if the speed is too high and it is impossible for the motor vehicle to safely drive through the curve or the comfort of the passengers is diminished.

Practical experiments have demonstrated that such a simple limitation of the curve speed increases safety, but does not take into consideration the desire of the passengers for comfortable driving conditions. It is frequently desired to have an adapted driving mode adjusted before a situation occurs, in which the automatic control influences the control of the vehicle for safety reasons (expanded speed control).

The objective of this aspect of the invention consists of disclosing a method and a device for adapting the curve speed.

[This objective is attained with the characteristics of Claims 127 and 134. The respective subordinate claims pertain to preferred embodiments of this method and this device.]

In the method for automatically adapting the speed of the motor vehicle to a curve, the absolute speed of the vehicle is initially determined. The method utilizes already known variables and may be implemented in a motor vehicle and actuated independently or in connection with a distance controller and/or a speed controller. A combined system provides certain advantages because all known systems partially utilize the same actuators and sensors. In this case, the driving situations, during which the system intervenes, and the intended effects of the systems are, however, different.

In the following description, the term longitudinal dynamic control refers to a speed control as well as a distance control or any other control which influences the speed of the motor vehicle.

The method according to the invention for automatically adapting the speed of the motor vehicle to a curve is characterized by determining a transverse acceleration of the motor vehicle. This transverse acceleration may either be measured directly with an acceleration sensor or determined from the yaw rate and the motor vehicle speed if at least one axle of the motor vehicle is not subject to a transverse drift. The determined transverse acceleration is compared with a predetermined transverse reference acceleration, and a corresponding speed correction signal is output. Based on this speed correction signal, an intermediate acceleration value is determined such that a transverse limiting acceleration is not exceeded in the curve.

This takes place without requiring an active intervention by the driver. Once the motor vehicle has driven through the curve and enters a straight roadway again, the transverse acceleration drops to zero. A control intervention in the sense of a curve speed adaptation is no longer required in this case.

The transverse reference acceleration, with which the actual transverse acceleration is compared and which may correspond to the limiting acceleration, lies between approximately 2 and 3 m/s^2 for comfortable driving conditions.

The advantage of the method according to the invention is that the absolute speed of the motor vehicle is adapted to the radius of the curve while driving through curves, so that the transverse acceleration stays within a range of values for maintaining comfort. In motor vehicles with cruise control, it is advantageous that the nominal speed be always maintained at the value adjusted for a straight roadway. Consequently, the driver need not switch off the speed controller function or reprogram the speed controller before and after each curve.

The device according to the invention consists of a control device for automatically adjusting the speed.

The control device according to the invention is characterized by means for determining a transverse acceleration of the motor vehicle and a comparison device for comparing the transverse acceleration with a reference transverse acceleration and for outputting the speed correction signal in the form of an intermediate acceleration value.

[One embodiment of the method according to the invention and the device according to the invention is described below with reference to the figures, where

Figure 36 shows the process sequence of one embodiment of the method according to the invention, and

Figure 37 shows one embodiment of a controller according to the invention.]

Figure 36 shows the process sequence of the method according to the invention in the form of a flow chart with the steps 10-S1 through 10-S3. After starting the system, the absolute speed of the motor vehicle is initially determined. This is usually realized with the aid of the motor vehicle speedometer. However, it would also be conceivable to determine the rotational speed of the individual wheels, particularly if the motor vehicle is equipped with an ABS control.

In order to maintain a comfortable curve speed, the transverse acceleration a_{trans} is determined in step 10-S1. A person skilled in the art is familiar with various options for determining the transverse acceleration a_{trans}. The direct determination of the transverse acceleration is realized with the aid of a suitably installed acceleration sensor. This sensor directly measures an acceleration component that acts upon the motor vehicle perpendicular to the longitudinal vehicle direction, in the horizontal plane of the motor vehicle. Another option for determining the transverse acceleration consists of measuring the yaw rate (angular speed about the vertical axis of the motor

vehicle) and multiplying said yaw rate by the motor vehicle speed (the tangential speed along the curve). The second option for determining the transverse acceleration provides the advantage that a separate acceleration sensor can be eliminated because a yaw rate sensor is already provided in many motor vehicles. For example, (oscillatory) gyroscopes are utilized as yaw rate sensors. If this sensor should also be eliminated, it is possible to utilize the ABS control and determine the yaw rate from the rotational speed of the wheels. In addition, the yaw rate may also be determined from an output signal of a steering wheel position sensor and the absolute motor vehicle speed.

The measured or determined transverse acceleration is compared with the acceleration limiting value (step 10-S2). A differential signal that is converted into a speed correction signal in the form of an intermediate acceleration value and subsequently output (step 10-S3) results from the comparison of these two variables.

In order to make it possible to carry out a continuous adaptation of -S1 after step 10-S3 and continues with the steps 10-S1 through 10-S3.

The control device for realizing this method is illustrated in Figure 37. This control device contains means 10-1 for determining the absolute speed. In order to correct the absolute speed while driving through curves, the control device according to the invention is provided with means 10-2 for determining the transverse acceleration. This may pertain to the various types of sensors described above, namely a direct acceleration sensor or a combined speed and yaw rate sensor. The means for determining the transverse acceleration outputs an acceleration value that is compared with a reference value in a comparison device 10-3. The reference value corresponds to an acceleration at which the process of driving through a curve is still perceived as comfortable by the passengers.

A speed correction signal is derived from the comparison signal by the output device 10-4. This speed correction signal is incorporated into the method for controlling or regulating the motor vehicle in the form of an intermediate acceleration value.

The method according to the invention and the corresponding device make it possible to automate recurring operating processes, e.g., when entering and exiting freeways.

METHOD AND DEVICE FOR CONTROLLING OR REGULATING MOTOR VEHICLE

Abstract of the Disclosure

[Abstract]

The invention pertains to a method and a device for controlling or regulating a motor vehicle. Individual aspects of the invention pertain to methods for determining the nominal acceleration from several nominal accelerations, for adjusting a predetermined nominal acceleration, for realizing a motor vehicle follower control, for generating a high-quality speed signal, for processing a nominal speed, for actuating brake valves, for favorably realizing transition conditions, for controlling or regulating distances between motor vehicles, for operating a cruise control and for adjusting the speed around curves. The invention also pertains to devices for carrying out the respective methods.

[Figure 1]

R0065153.DOC

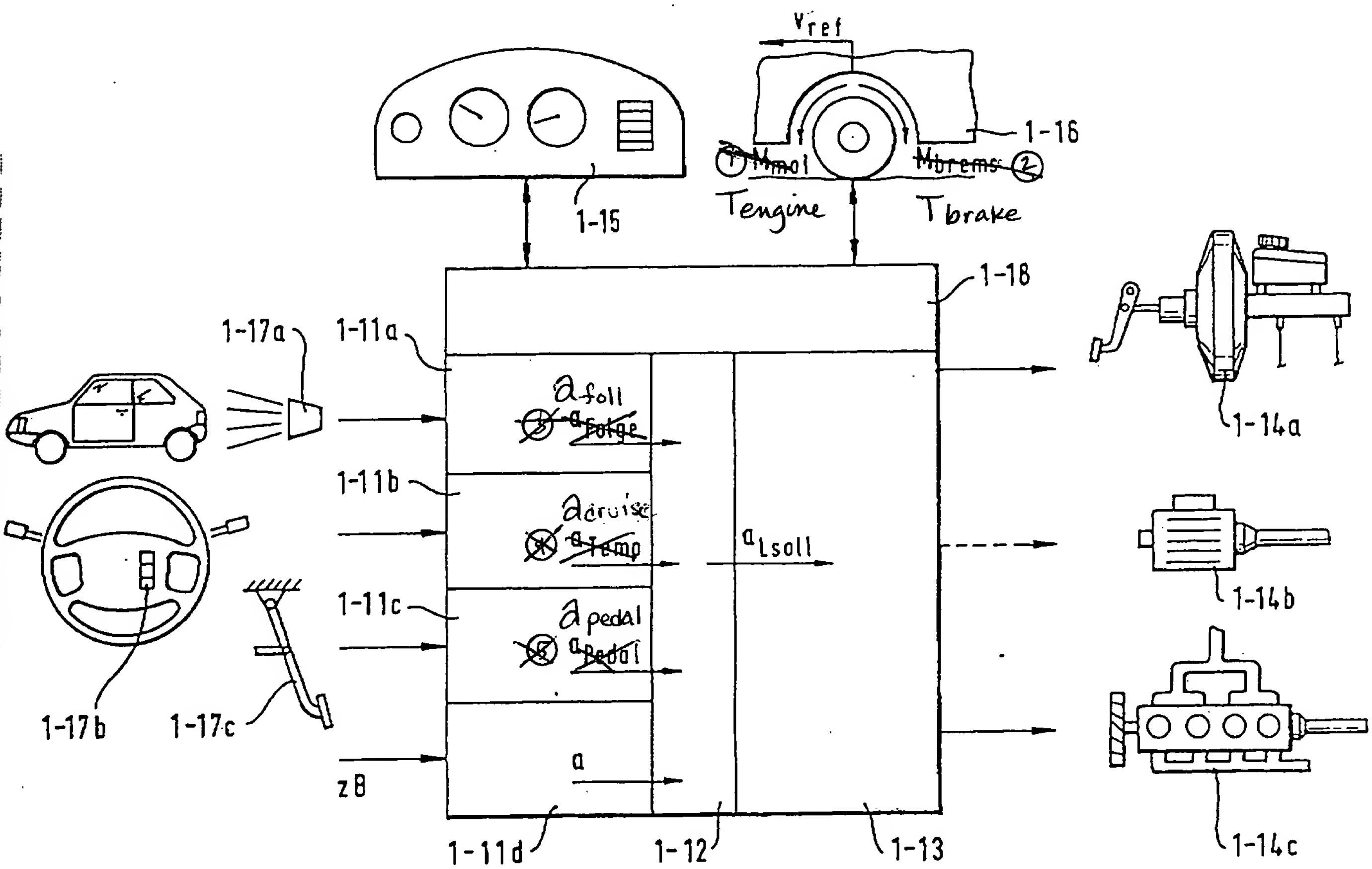
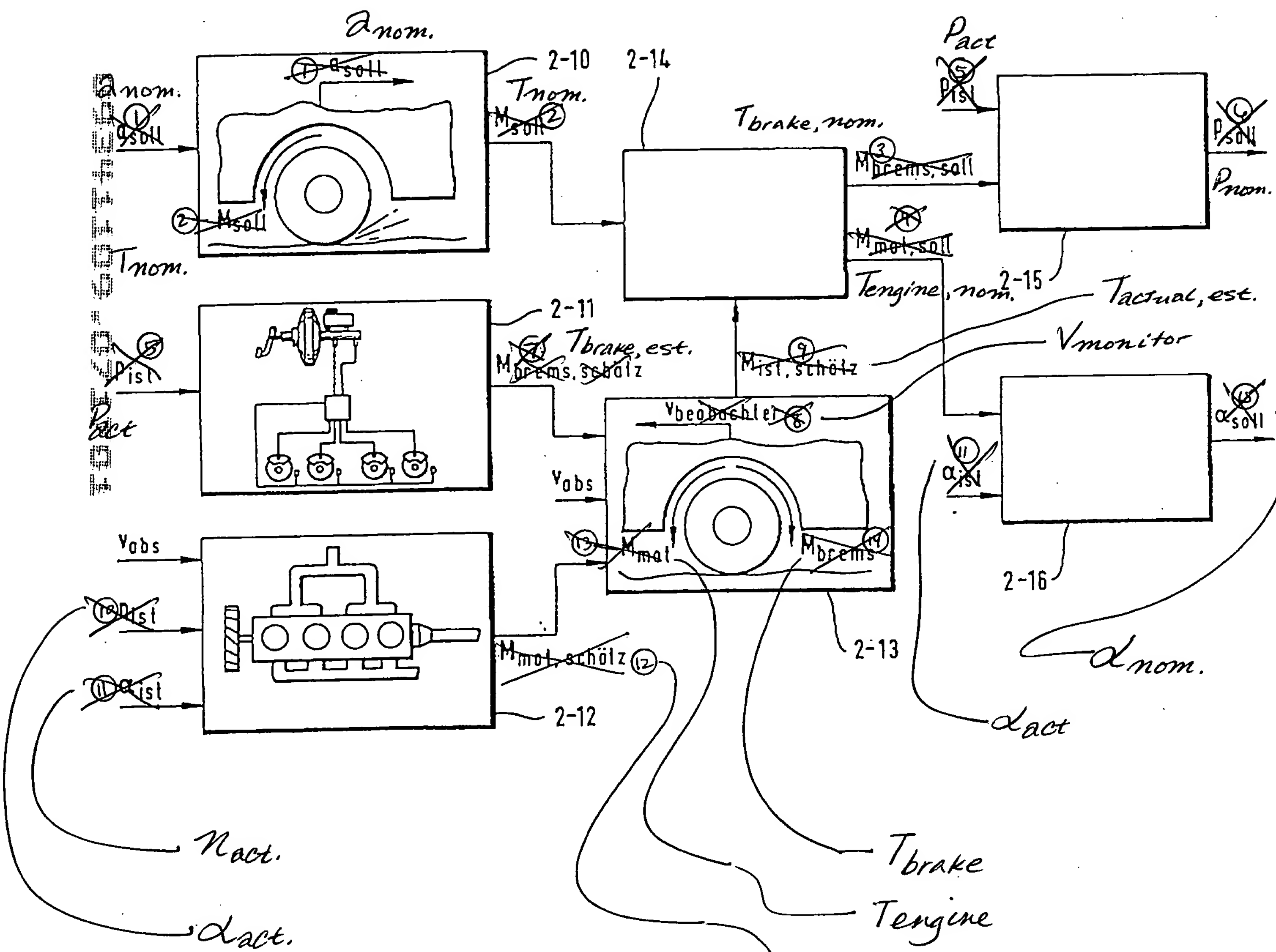

vref
1-16
1-15
~~Mmot~~
~~Mbrems~~
Tengine
Tbrake
1-18
1-17a
1-11a
afoll
~~aFolge~~
1-11b
acruise
~~aTemp~~
aLsoll
1-11c
apedal
~~aPedal~~
a
zB
1-17b
1-17c
1-11d
1-12
1-13
1-14a
1-14b
1-14c

Figure 1

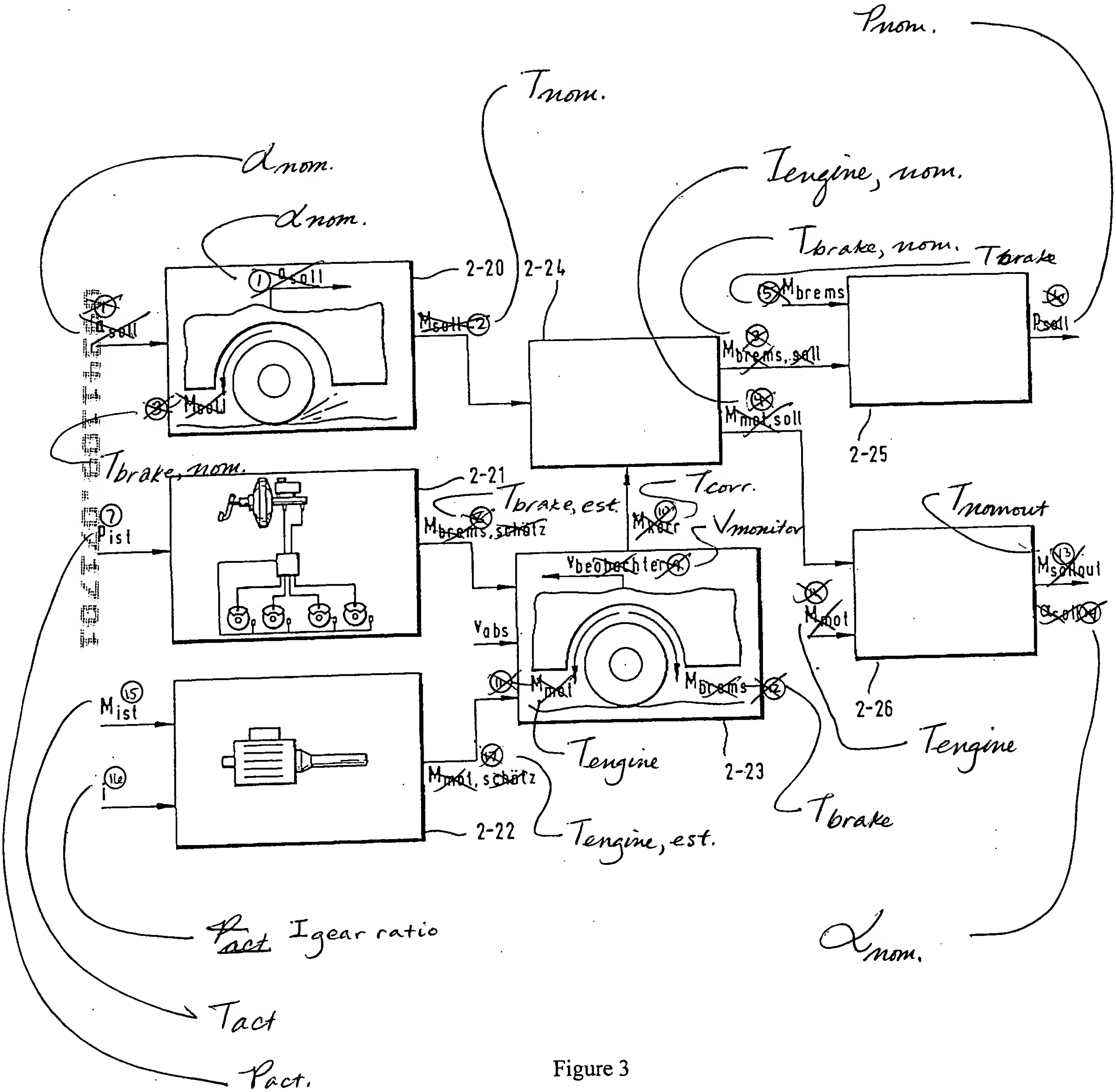
Key:	1	T_{engine}
	2	T_{brake}
	3	a_{foll}
	4	a_{cruise}
	5	a_{pedal}



anom.
Tnom.
2-10
2-14
Tbrake, nom.
Pact
Msoll
asoll
Mbrems, soll
Mmot, soll
Psoll
Pnom.
Tengine, nom.
2-15
Tactual, est.
2-11
Tbrake, est.
Mbrems, schätz
Mist, schätz
Vmonitor
Vbeobachtet
Pist
αsoll
αist
Vabs
Mmot
Mbrems
2-16
2-13
Mmot, schätz
nist
2-12
αnom.
αact
nact.
αact.
Tbrake
Tengine
Tengine, est.

Figure 2

Key:	1	a_{nom}
	2	T_{nom}
	3	$T_{brake,nom}$
	4	$T_{engine,nom}$
	5	P_{act}
	6	P_{nom}
	7	$T_{brake,est}$
	8	$V_{monitor}$
	9	$T_{actual,est}$
	10	n_{act}
	11	α_{act}
	12	$T_{engine,est}$
	13	T_{engine}
	14	T_{brake}
	15	α_{nom}



Pnom.
Tnom.
αnom.
αnom.
Tengine, nom.
Tbrake, nom.
Tbrake
2-20
2-24
2-21
2-22
2-23
2-25
2-26
αsoll
Msoll
Mbrems
Psoll
Mbrems, soll
Mmot, soll
Tbrake, nom.
Tbrake, est.
Mbrems, schätz
Pist
Tcorr.
Mkorr
Vmonitor
vbeobachter
Tnomout
Msollout
αsoll
Mmot
vabs
Mmot
Mbrems
Mist
i
Mmot, schätz
Tengine
Tengine
Tengine, est.
Tbrake
Pact. Igear ratio
αnom.
Tact
Pact.

Figure 3

Key:	1	α_{nom}
	2	T_{nom}
	3	$T_{brake,nom}$
	4	$T_{engine,nom}$
	5	T_{brake}
	6	P_{nom}
	7	P_{act}
	8	$T_{brake,est}$
	9	$V_{monitor}$
	10	T_{corr}
	11	T_{engine}
	12	T_{brake}
	13	T_{nomout}
	14	α_{nom}
	15	T_{act}
	16	[gear ratio] I
	17	$T_{engine,est}$

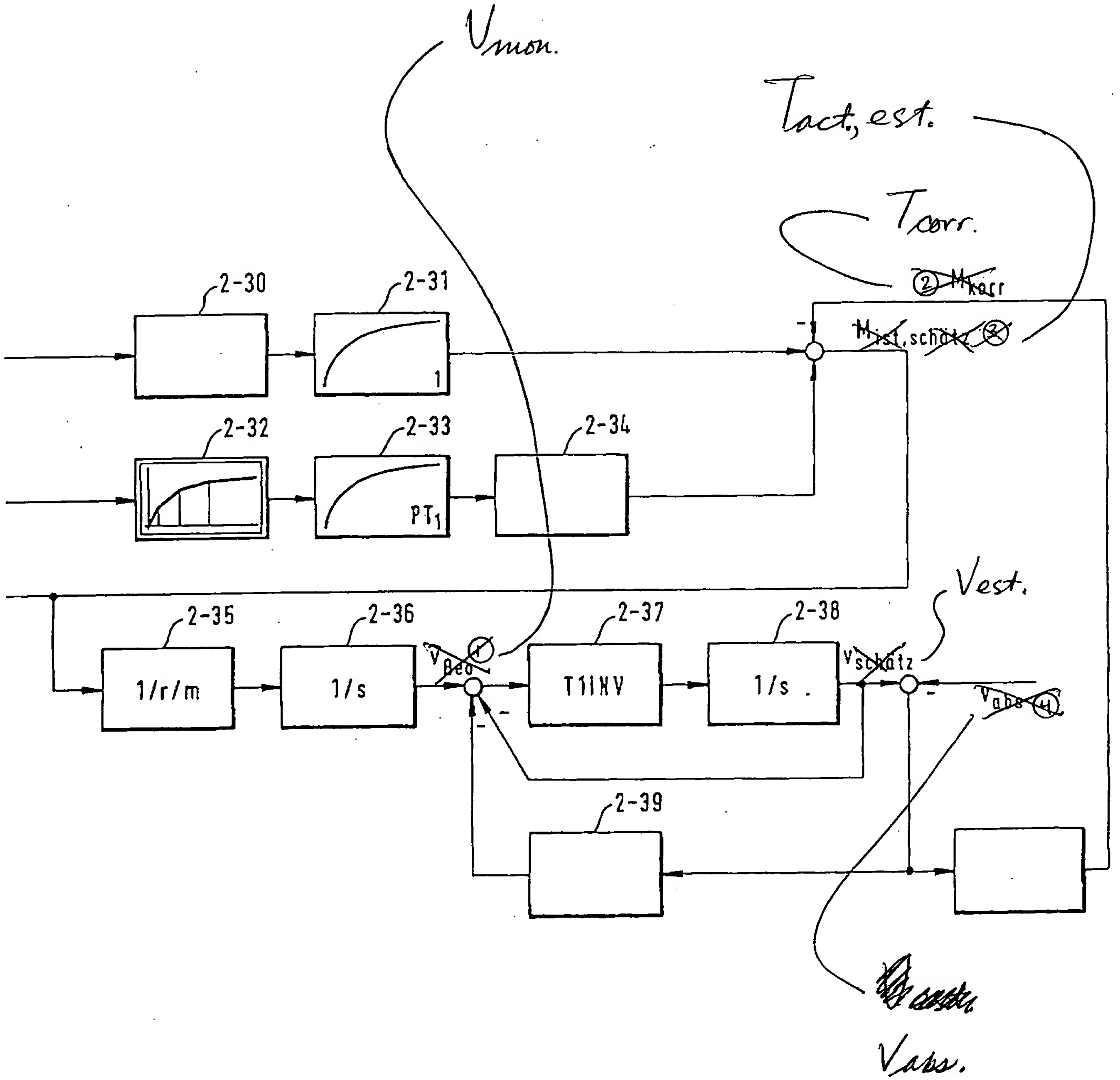

Vmon.
Tact,est.
Tcorr.
② ~~Mkorr~~
~~Mist,schätz~~ ③
2-30
2-31
1
2-32
2-33
PT1
2-34
2-35
1/r/m
2-36
1/s
~~vBeo~~ ①
2-37
T1INV
2-38
1/s
vschätz
Vest.
~~vabs~~ ④
2-39
Vabs.

Figure 4

Key:

1	V_{mon}
2	T_{corr}
3	$T_{act,est}$
4	$\cancel{V_{est}}$ V_{abs}

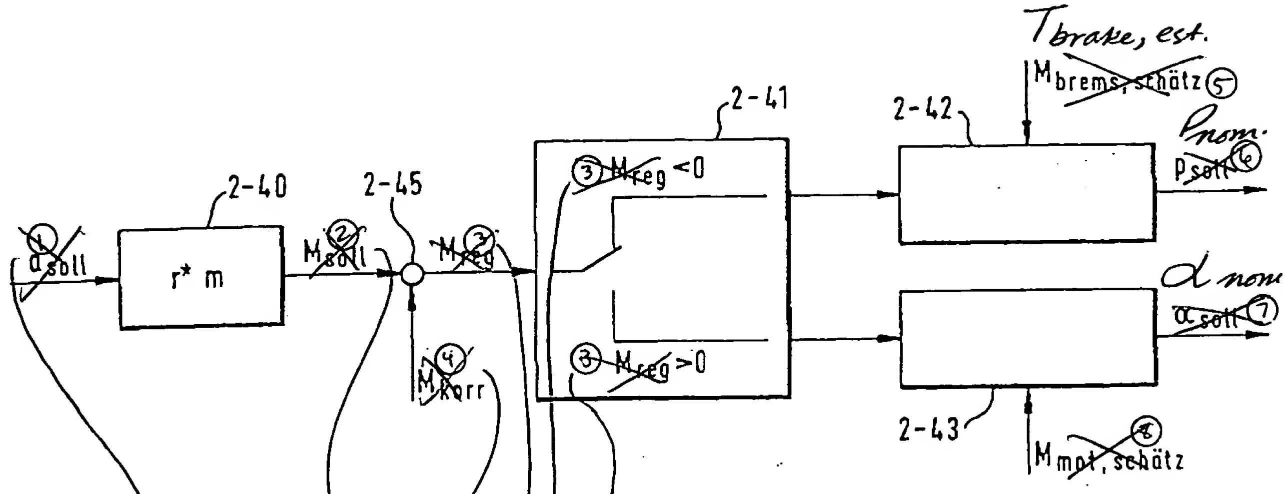


Figure 5

~~Key:~~
~~1~~ a_{nom}
~~2~~ T_{nom}
~~3~~ T_{ckl}
~~4~~ T_{corr}
~~5~~ $T_{brake,est}$
~~6~~ P_{nom}
~~7~~ α_{nom}
~~8~~ $T_{engine,est}$

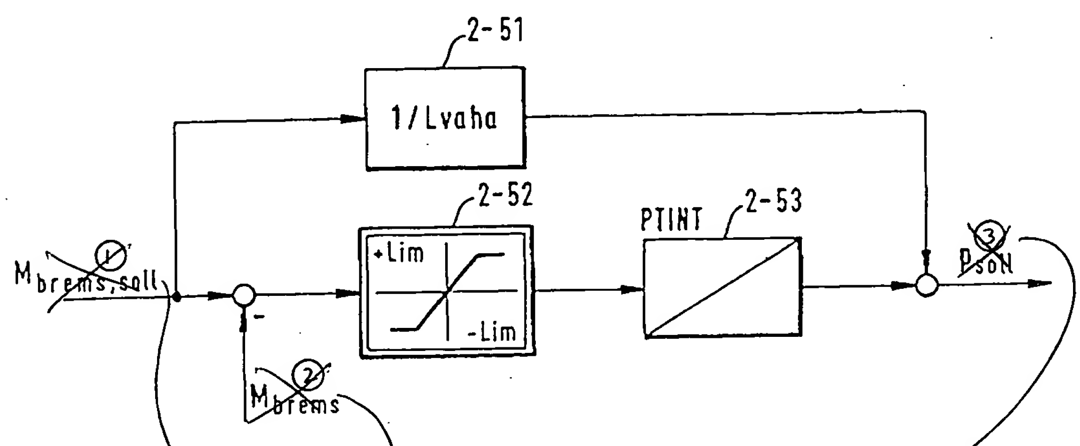


Figure 6

~~Key:~~
~~1~~ $T_{brake,nom}$
~~2~~ T_{brake}
~~3~~ P_{nom}

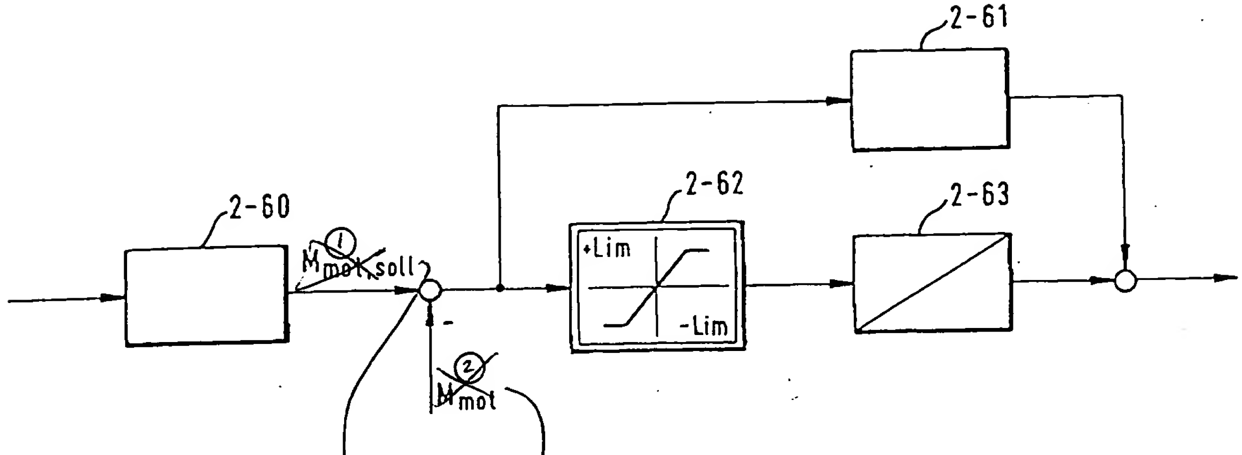


Figure 7

~~Key: 1~~ Tengine,nom
~~2~~ Tengine

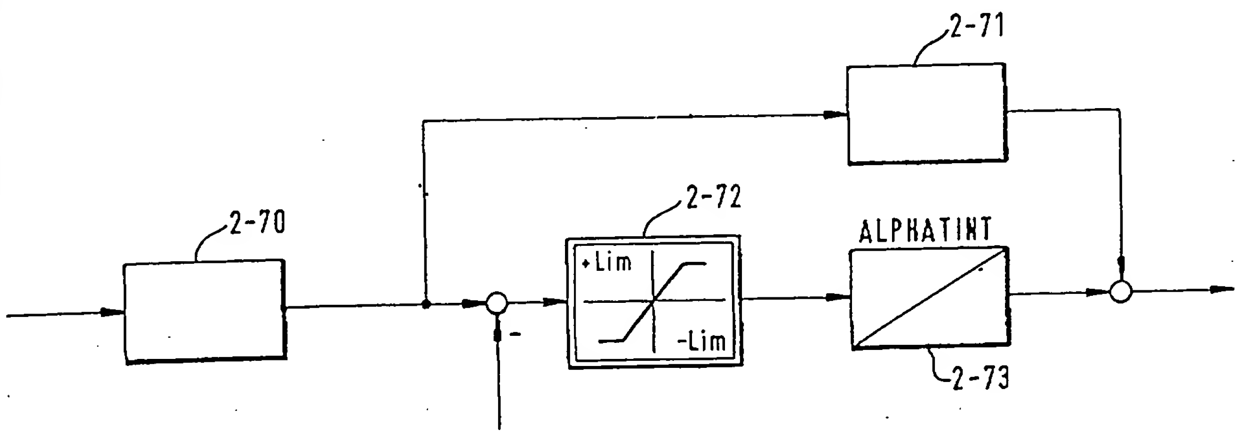


Figure 8

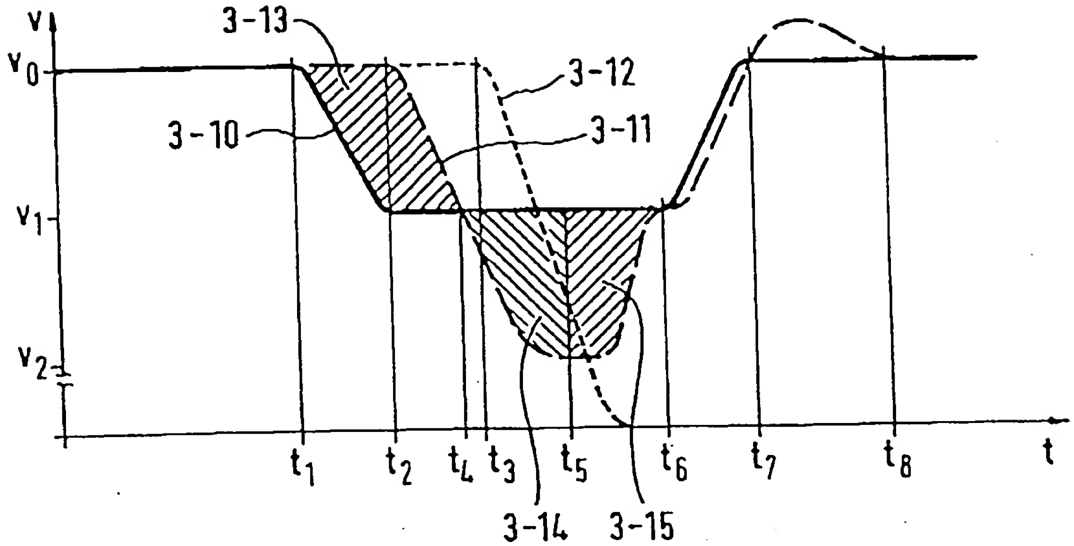


Figure 9

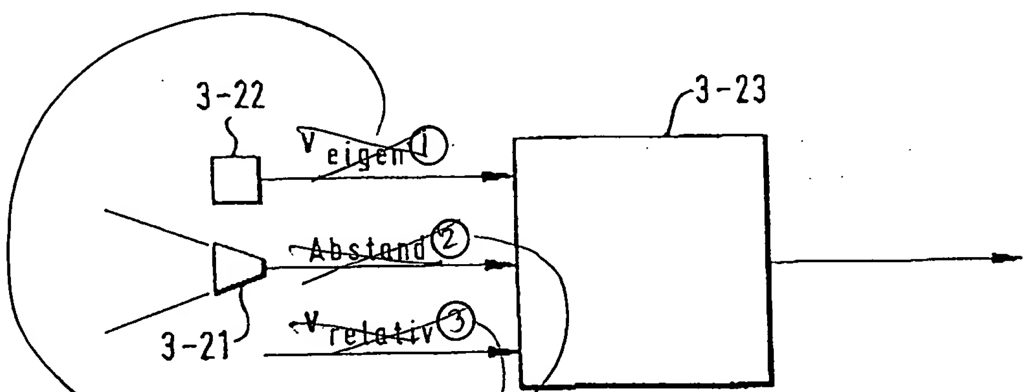


Figure 10

~~Key:~~ ~~1~~ V_{2ndcar}
~~2~~ Distance
~~3~~ $V_{relative}$

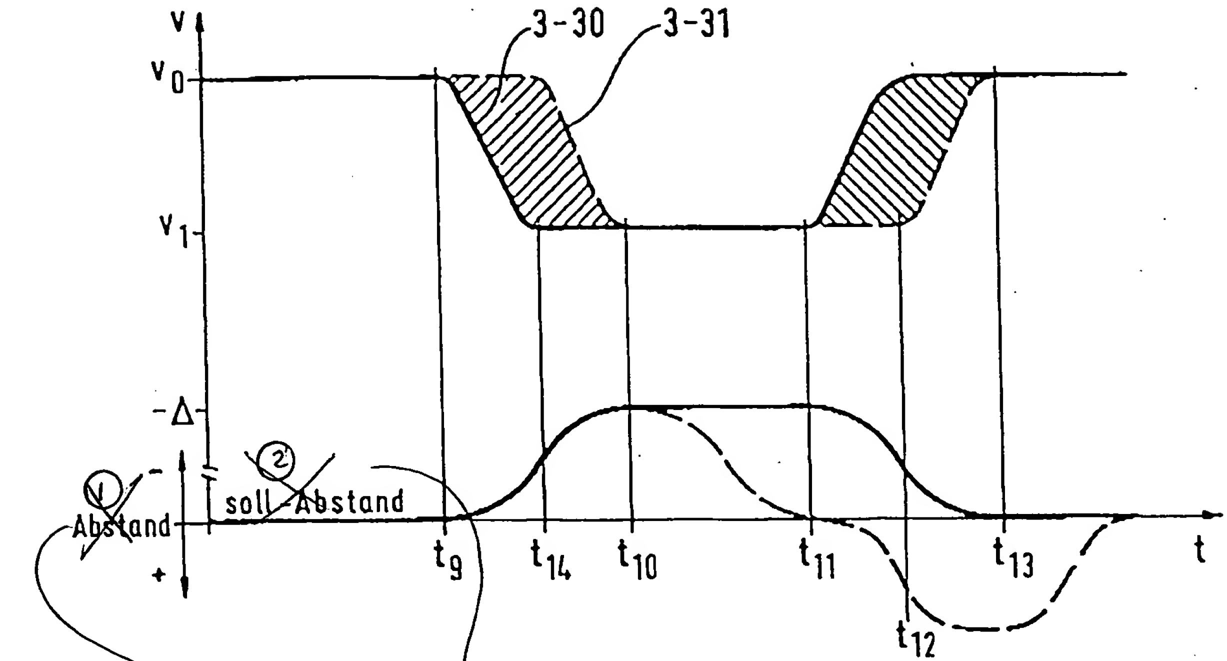
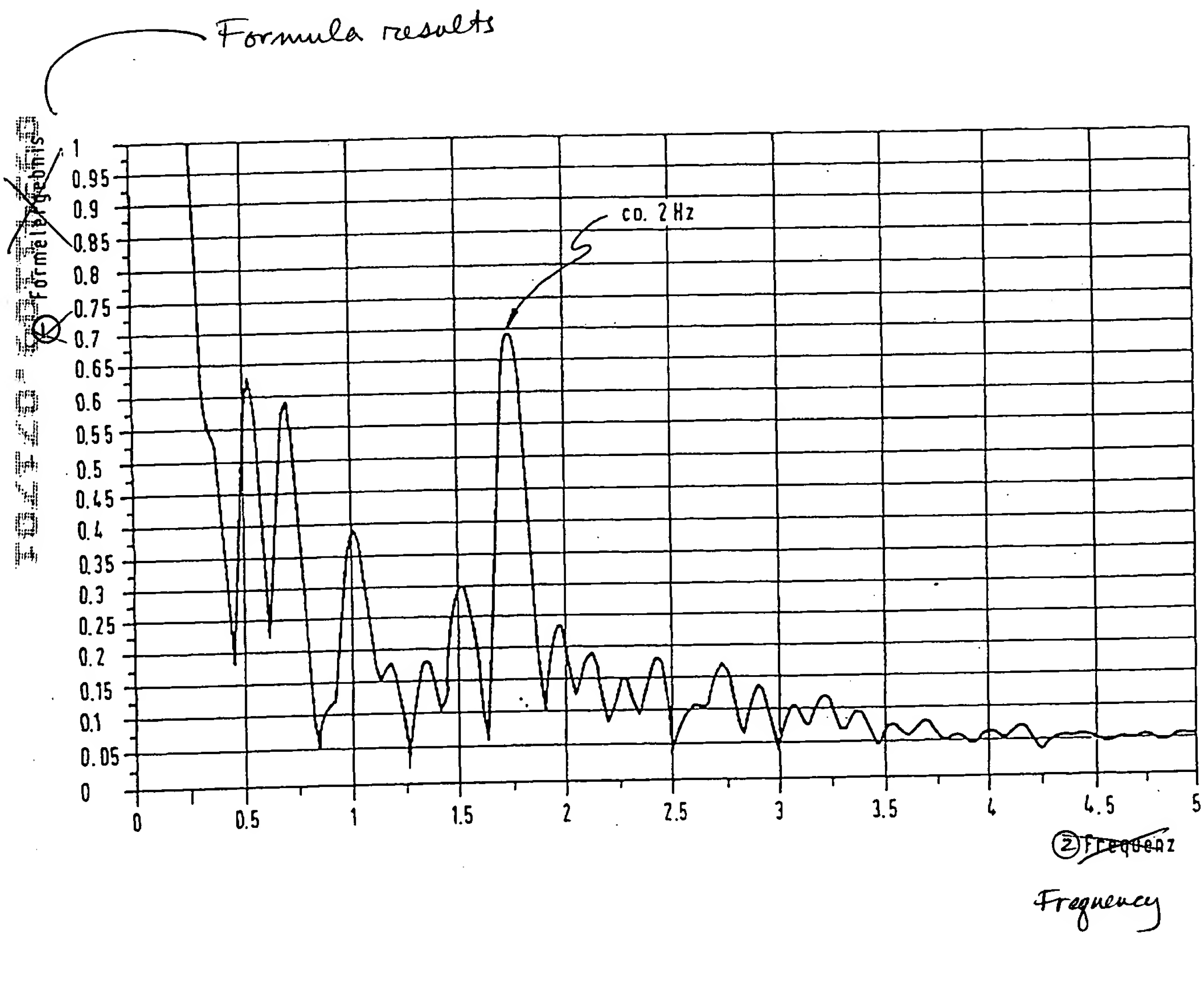


Figure 11

~~Key~~: ~~1~~ Distance
~~2~~ Nom.distance



Formula results
~~Formelergebnis~~
ca. 2 Hz
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
~~Frequenz~~
Frequency

Figure 12

~~Key: 1~~ ~~Formula~~ results
~~2~~ ~~Frequency~~

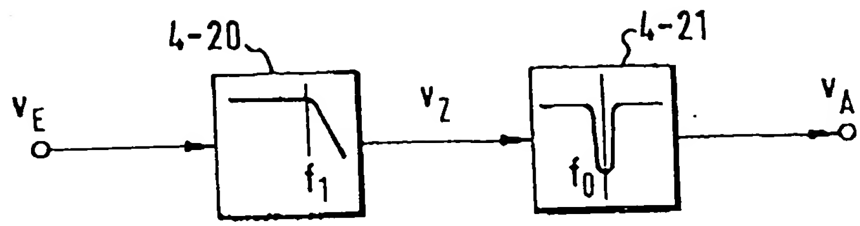


Figure 13

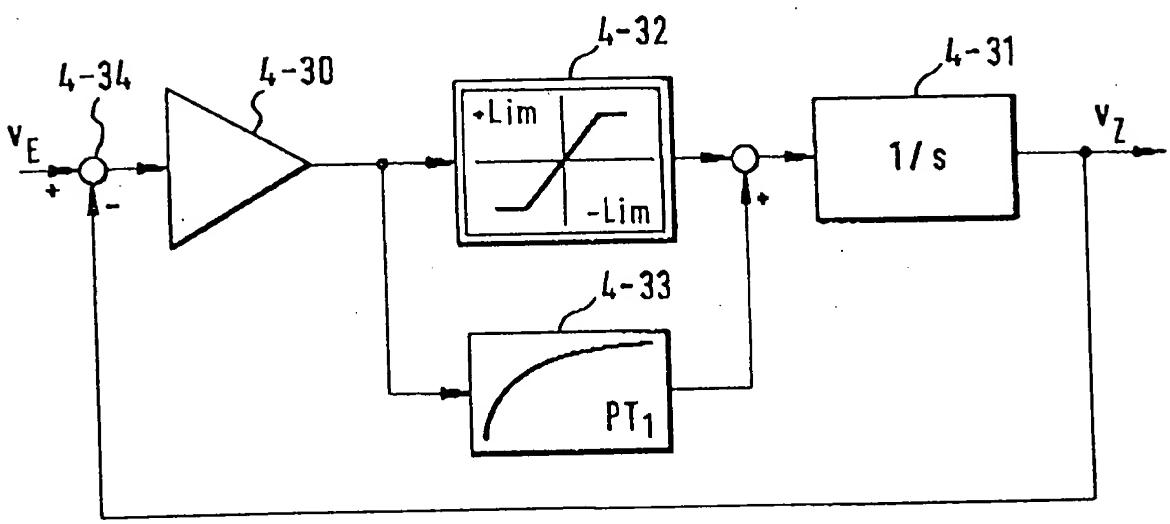


Figure 14

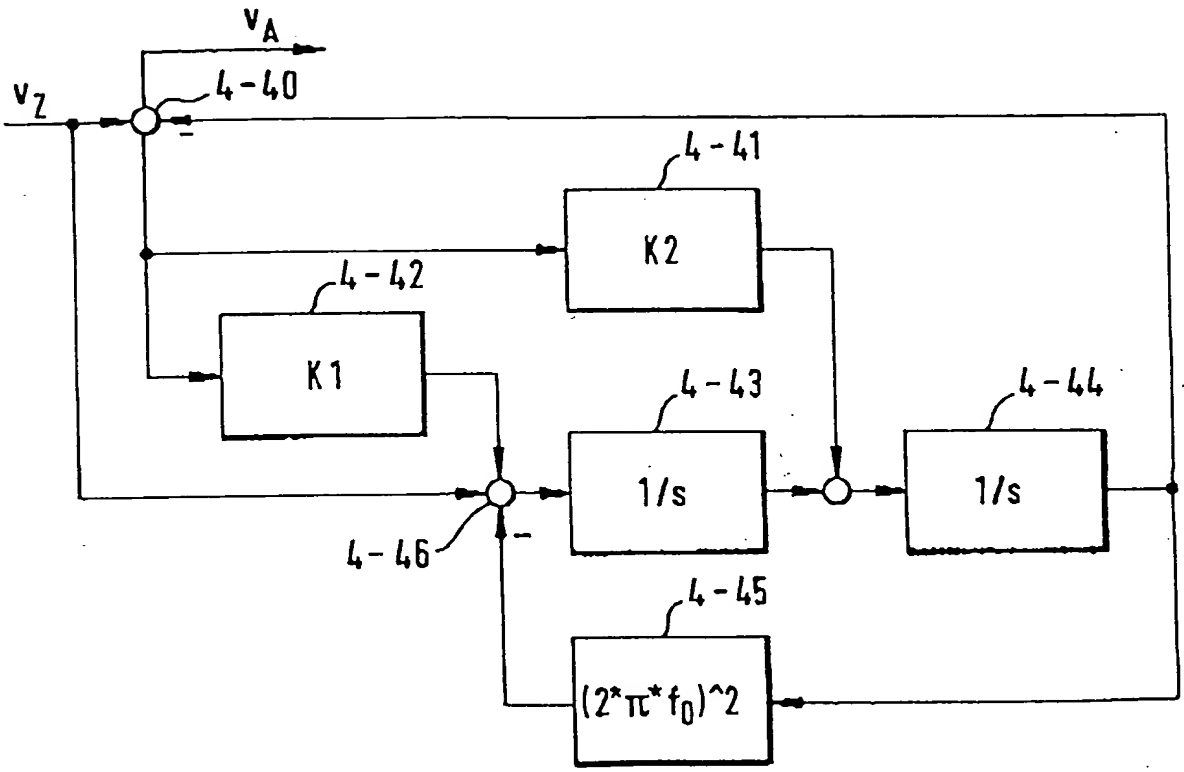


Figure 15

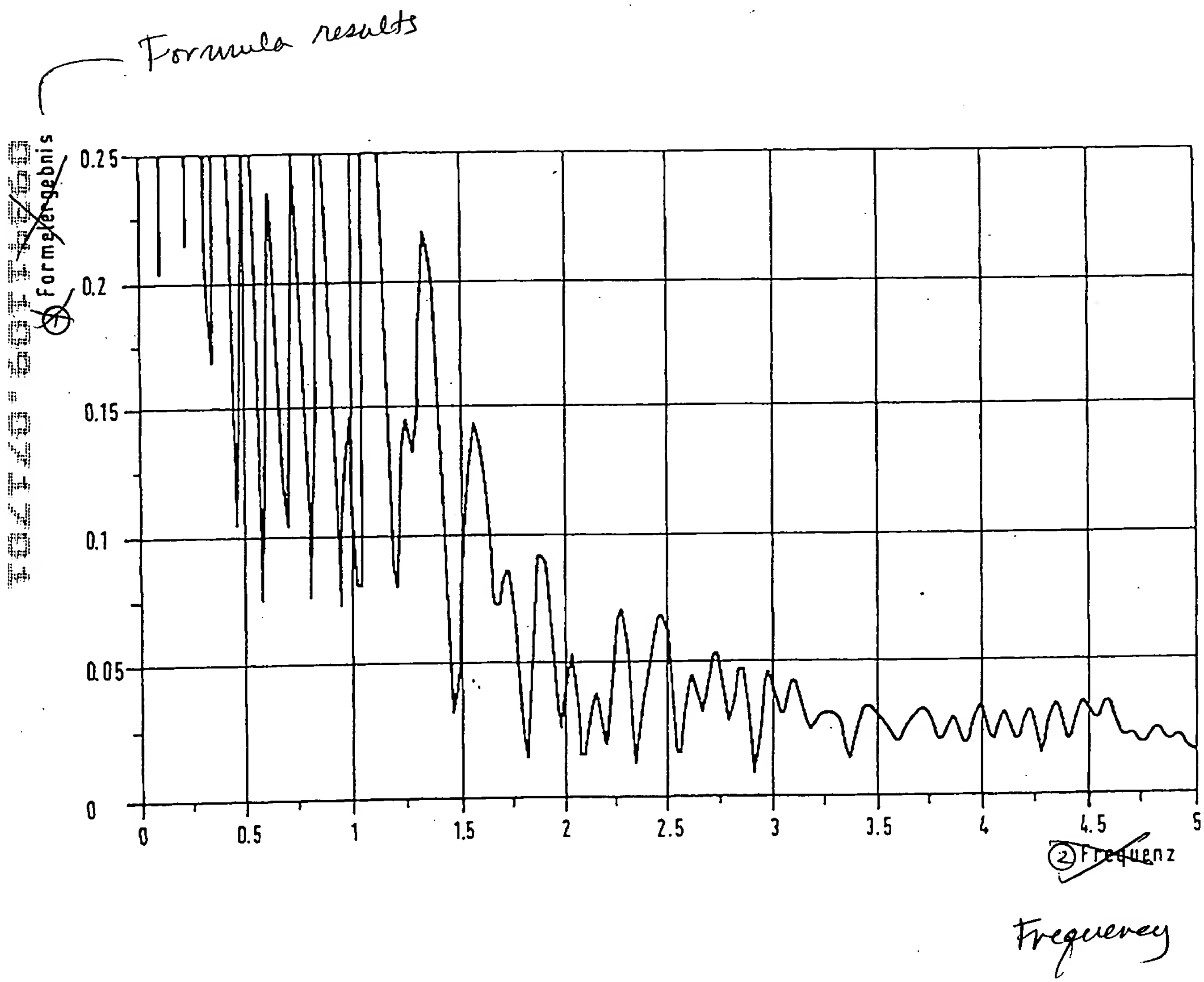

Formula results
~~Formelergebnis~~
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
~~Frequenz~~
Frequency

Figure 16

~~Key: 1~~ Formula results
~~2~~ Frequency

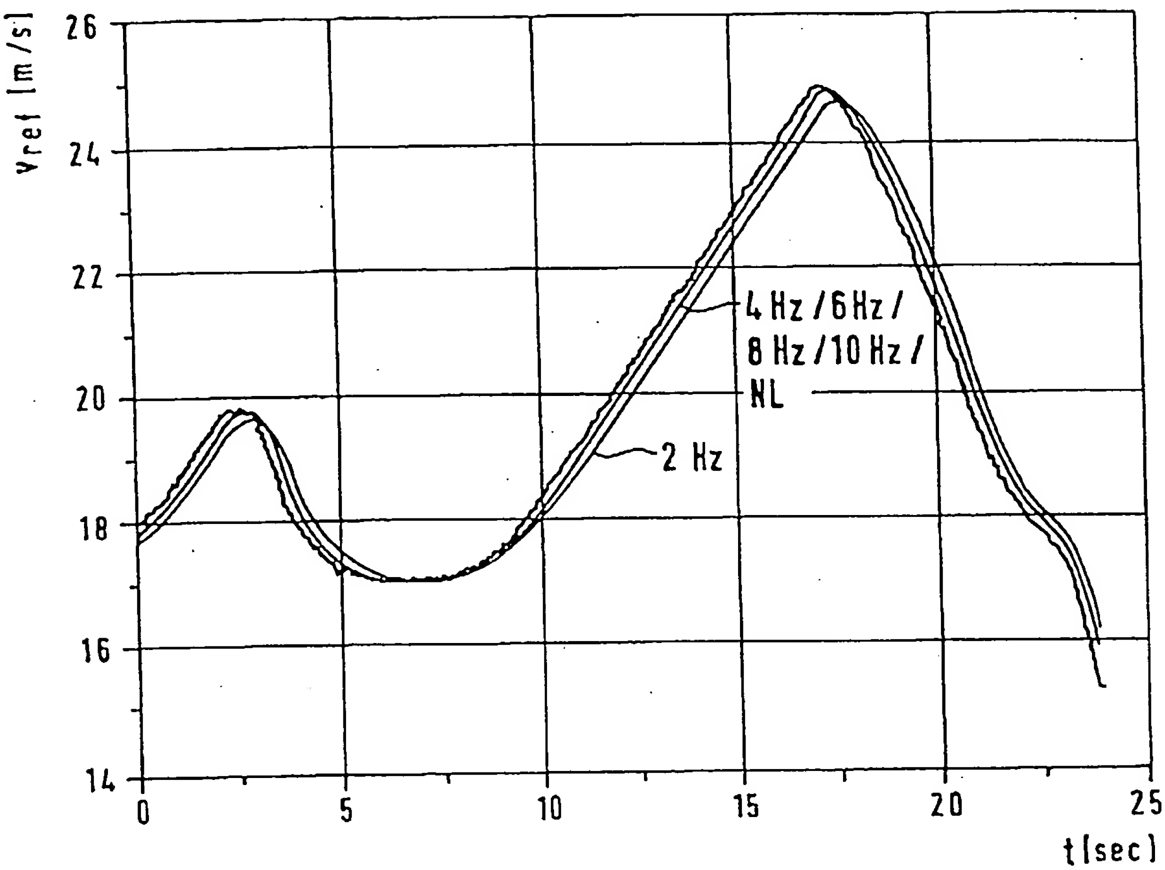


Figure 17

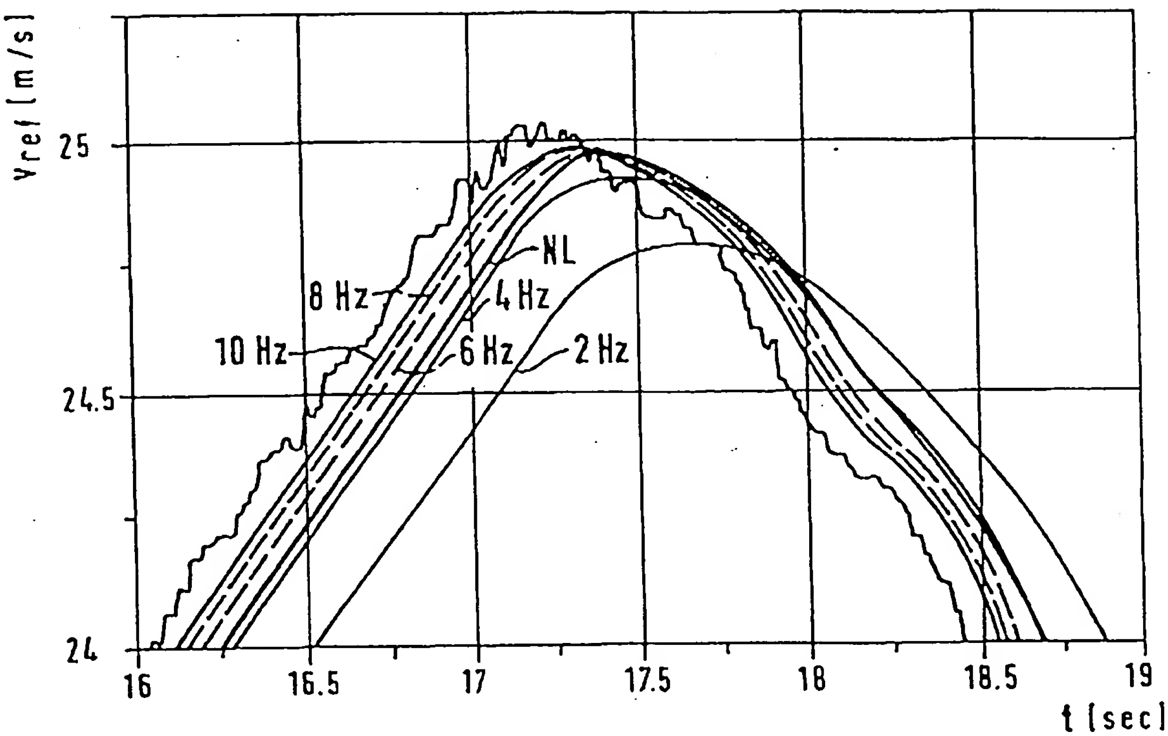

Vref [m/s]
25
24.5
24
16
16.5
17
17.5
18
18.5
19
t [sec]
NL
8 Hz
4 Hz
10 Hz
6 Hz
2 Hz

Figure 18

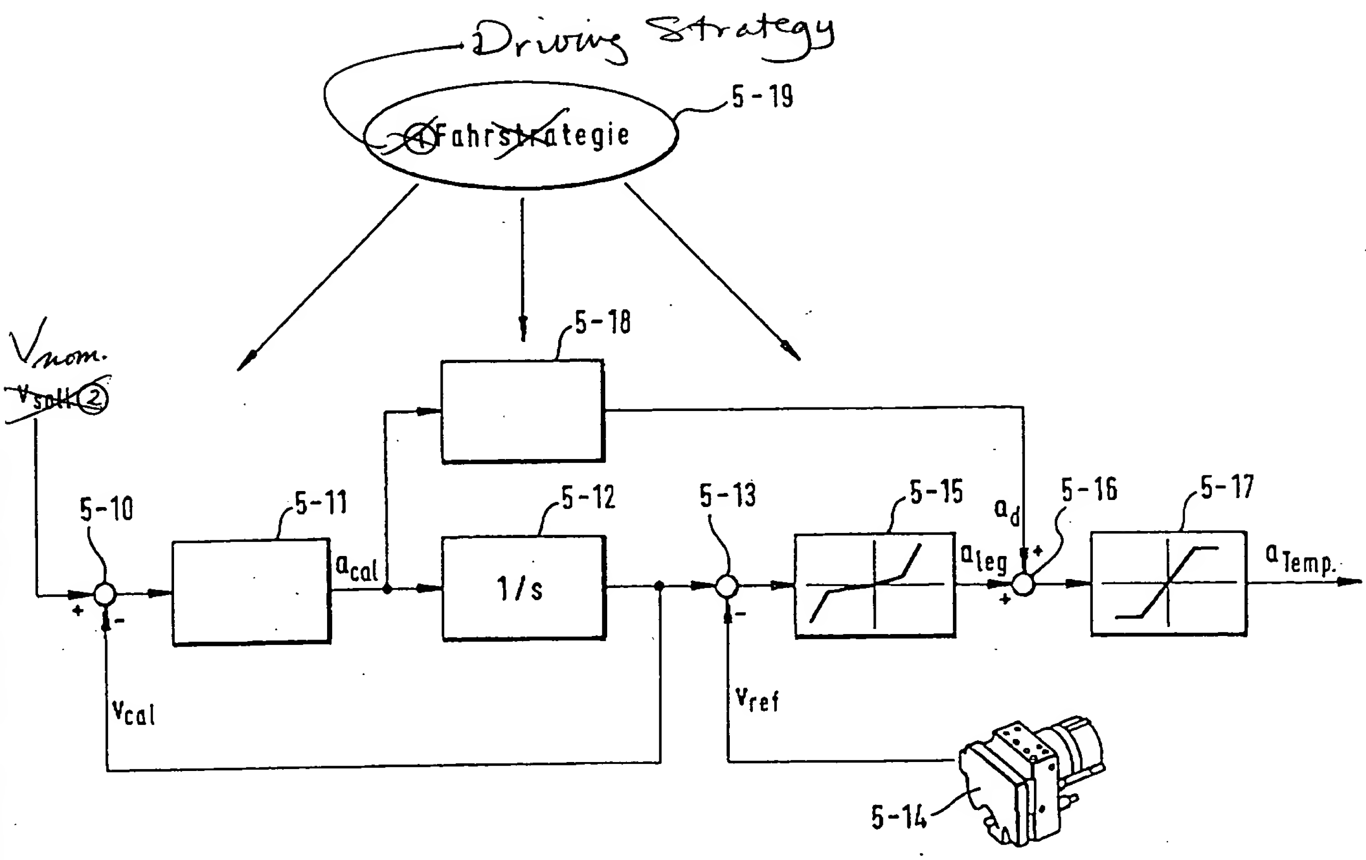


Figure 19

~~Key: 1~~ Driving strategy
~~2~~ V_{nom}

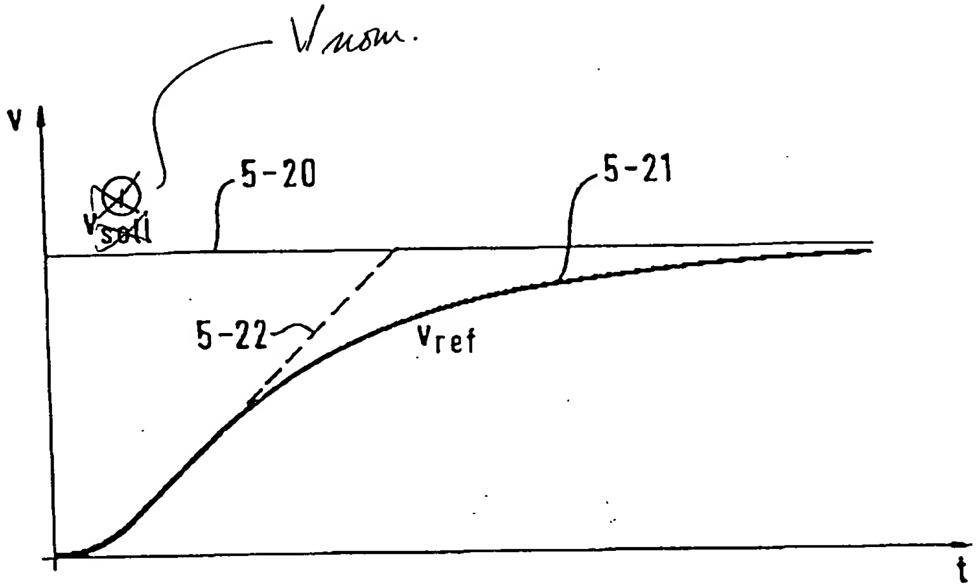


Figure 20

~~Key: 1~~ ~~V_{nom}~~

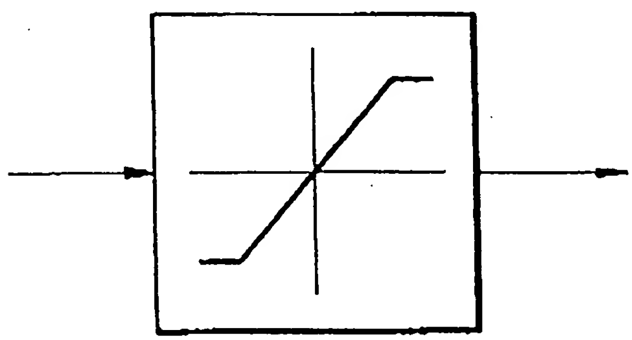


Figure 21

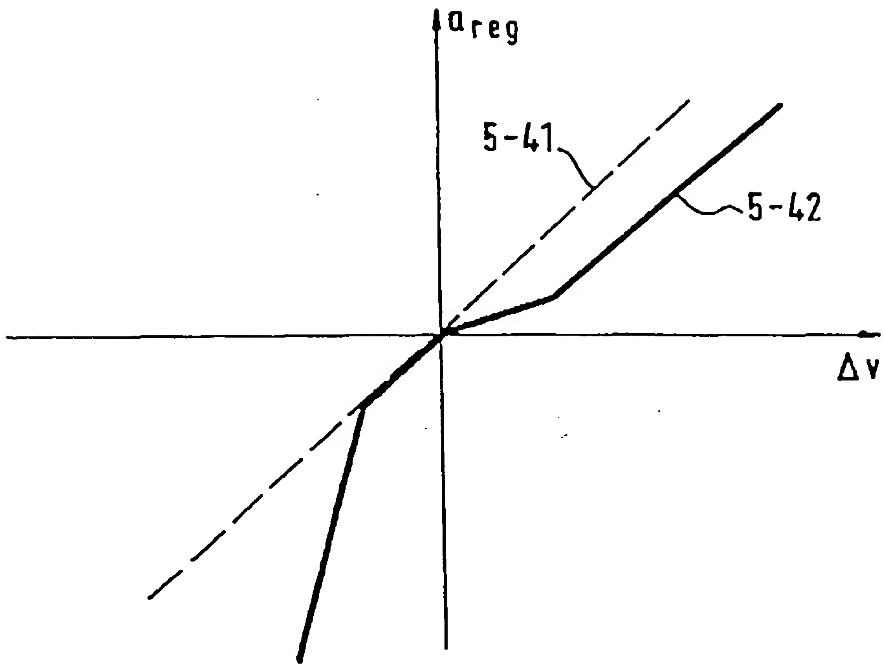


Figure 22

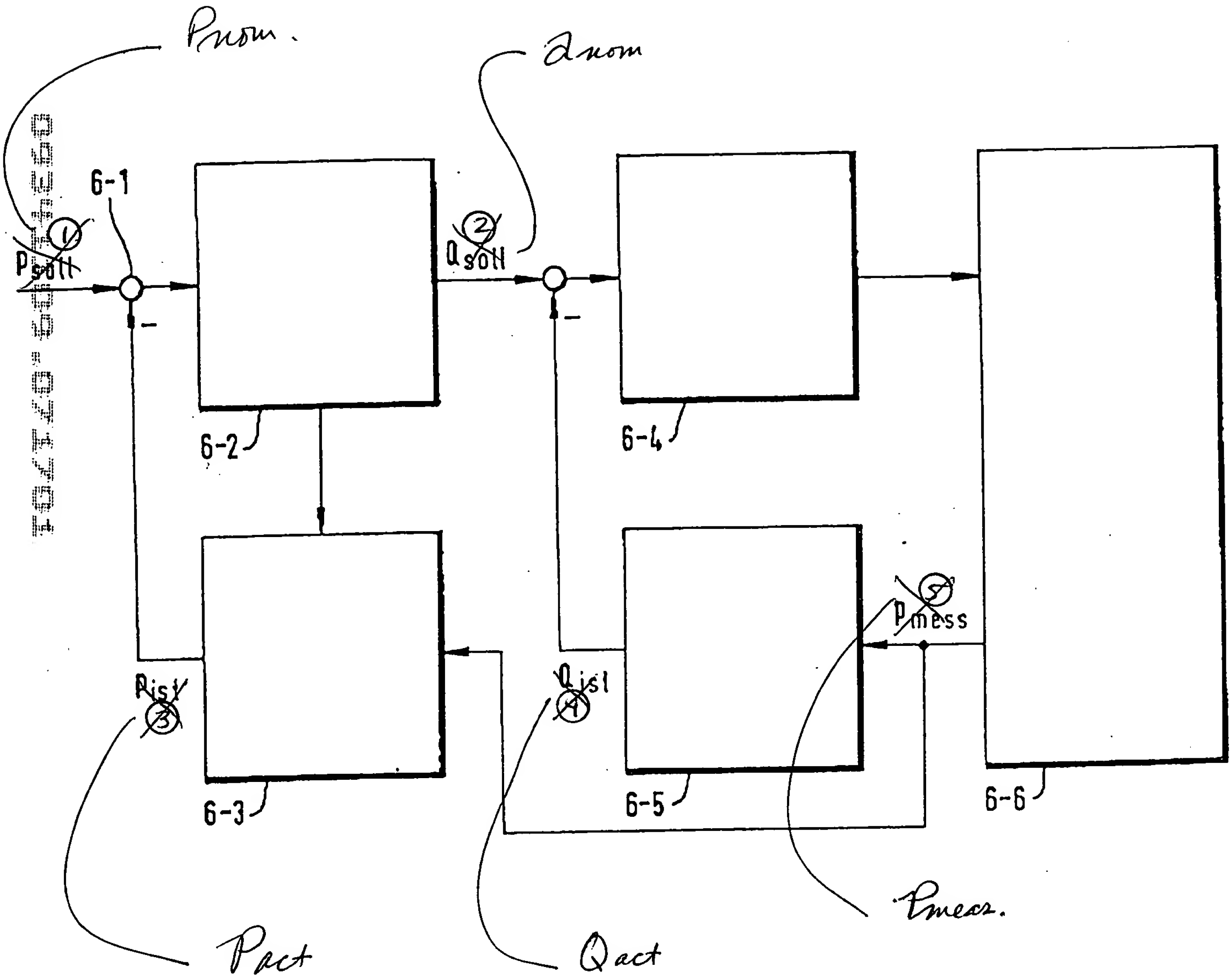

Pnom.
Qnom
6-1
1
Psoll
2
Qsoll
6-2
6-4
5
Pmess
Pist
3
Qist
4
6-3
6-5
6-6
Pmeas.
Pact
Qact

Figure 23

Key: 1 P_{nom}
2 a_{nom}
3 P_{act}
4 Q_{act}
5 P_{meas}

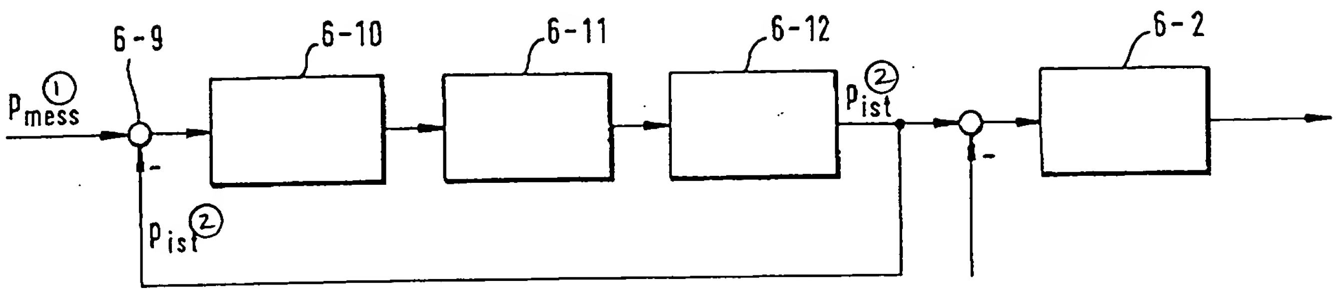


Figure 24

Key: 1 P_{meas}
2 P_{act}

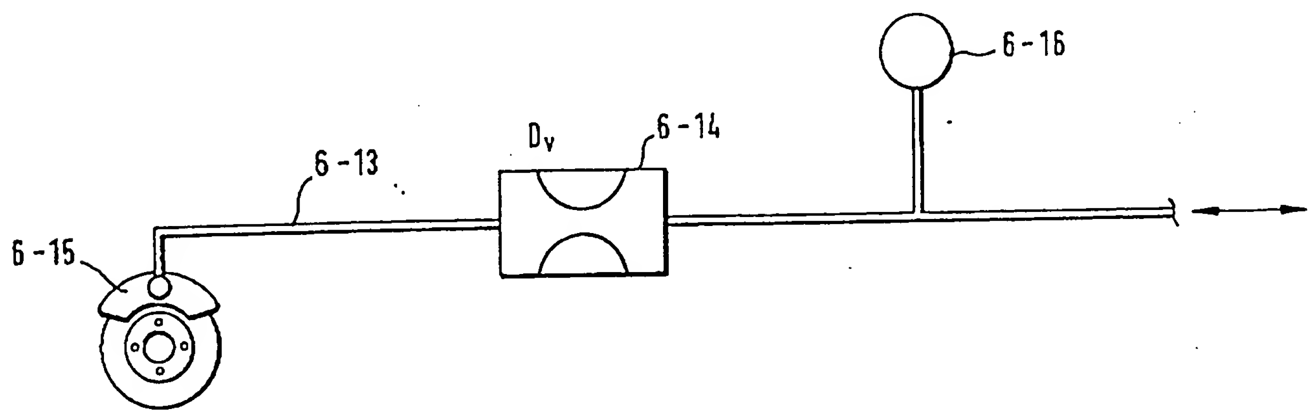


Figure 25

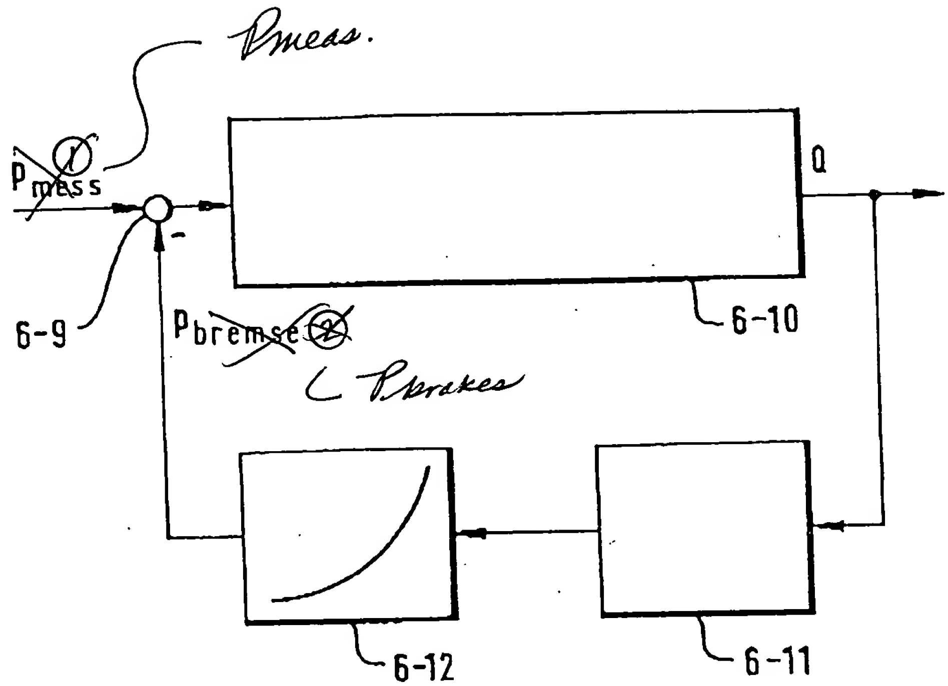


Figure 26a

~~Key:~~ ~~1~~ ~~P_{meas}~~
~~2~~ ~~P_{brakes}~~

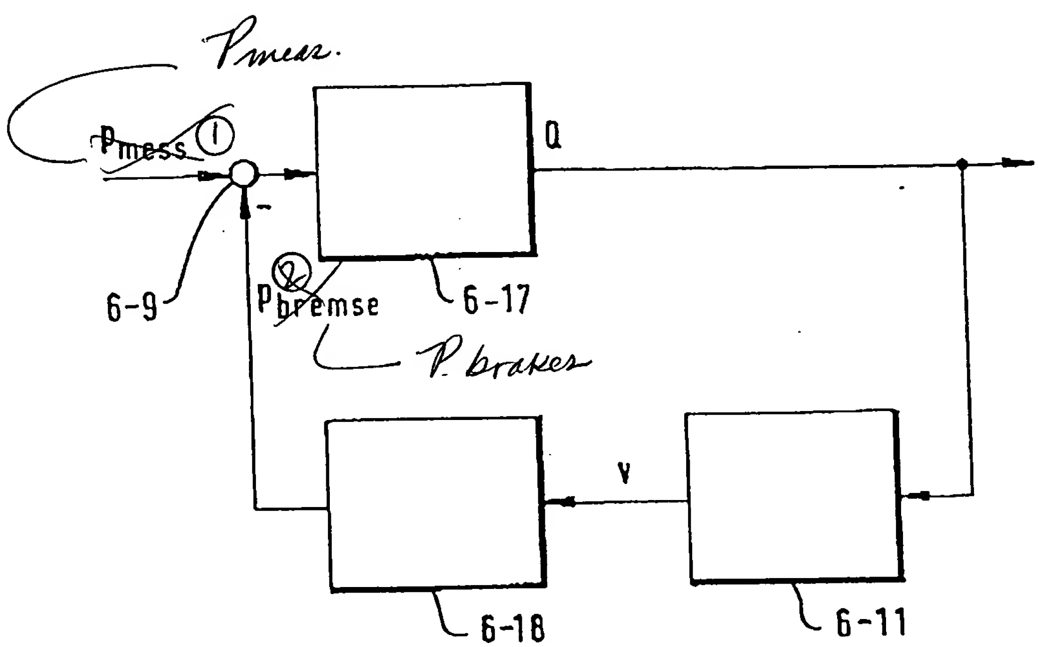


Figure 26b

~~Key: 1~~ ~~P_{meas}~~
~~2~~ ~~P_{brakes}~~

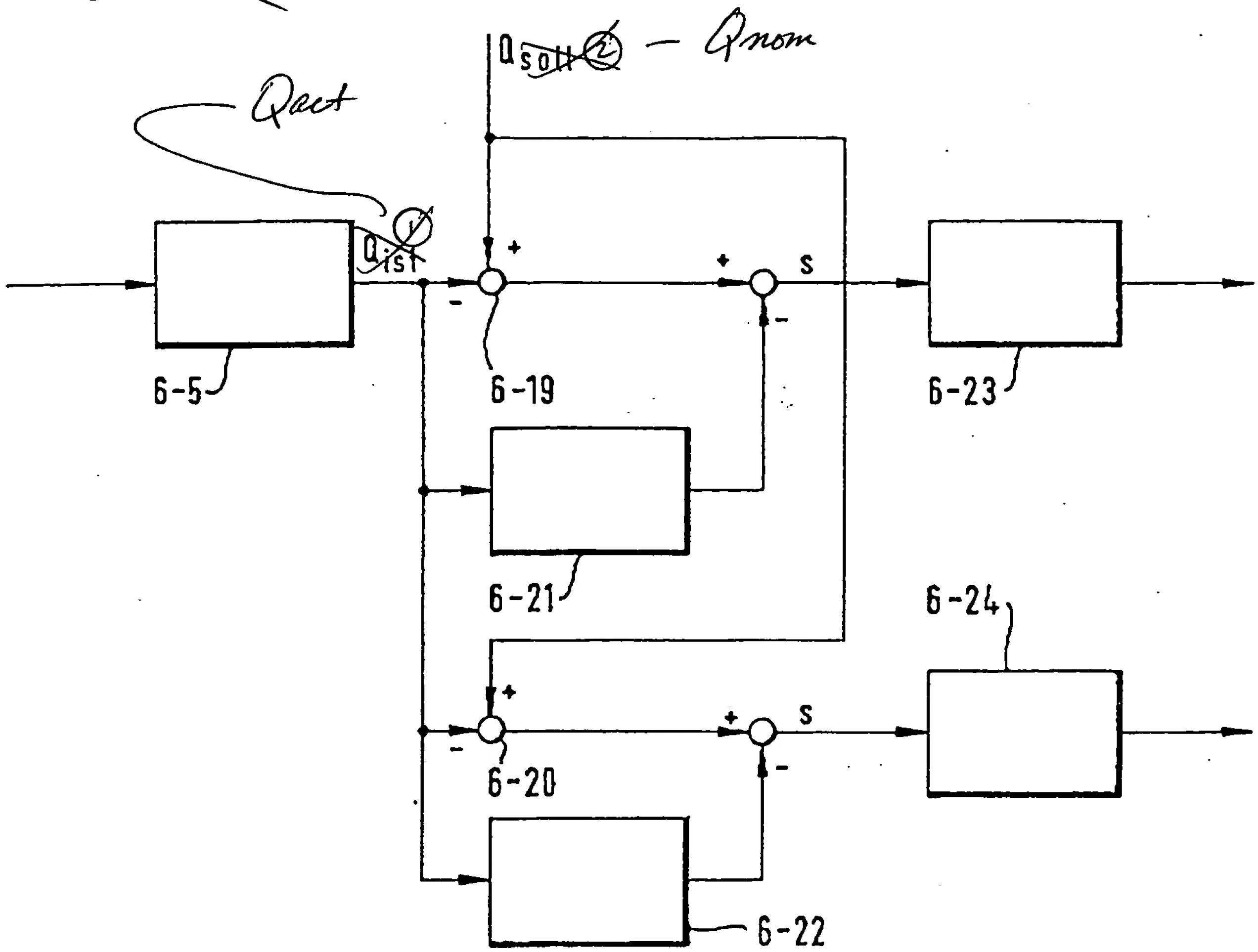


Figure 27

~~Key: 1~~ ~~Q_{act}~~
~~2~~ ~~Q_{nom}~~

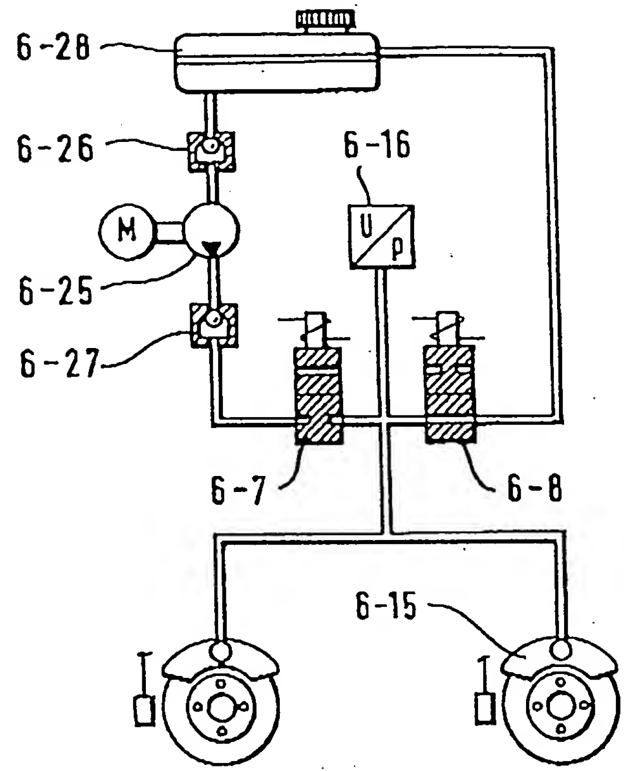


Figure 28

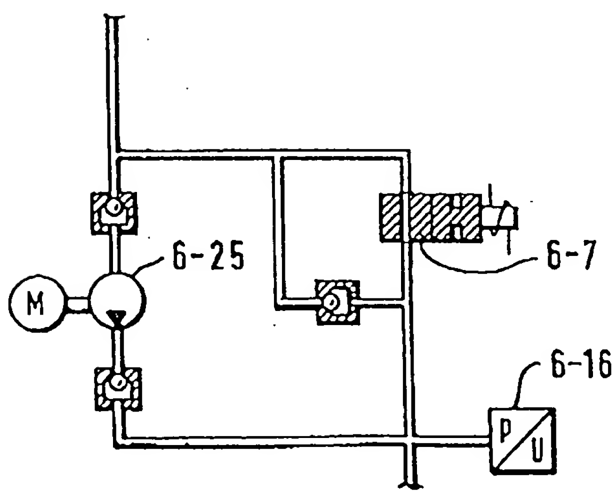


Figure 29

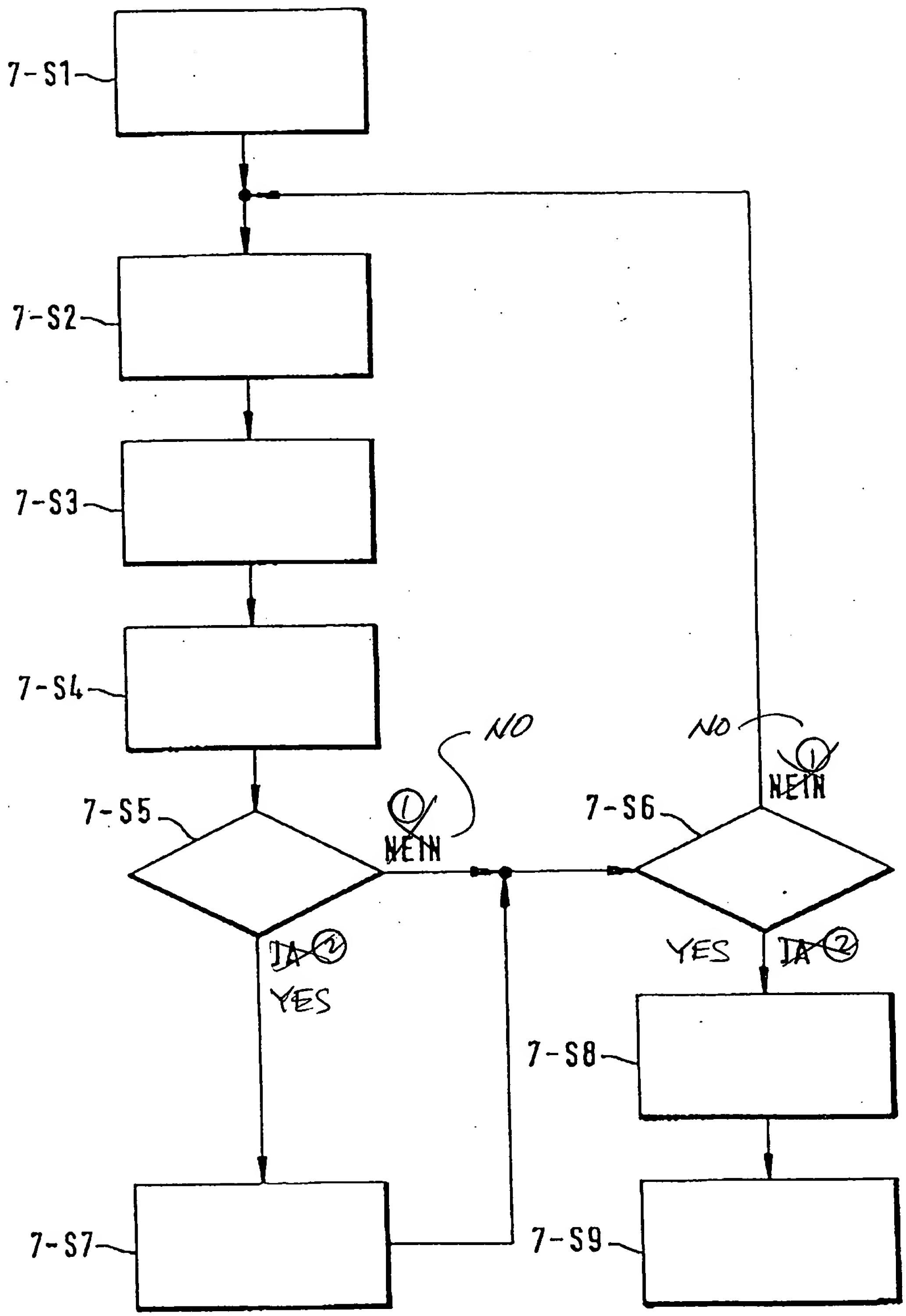

7-S1
7-S2
7-S3
7-S4
7-S5
7-S6
7-S7
7-S8
7-S9
NO
1
~~NEIN~~
NO
1
~~NEIN~~
~~JA~~ 2
YES
YES
~~JA~~ 2

Figure 30

~~Key: 1 No~~
~~2 Yes~~

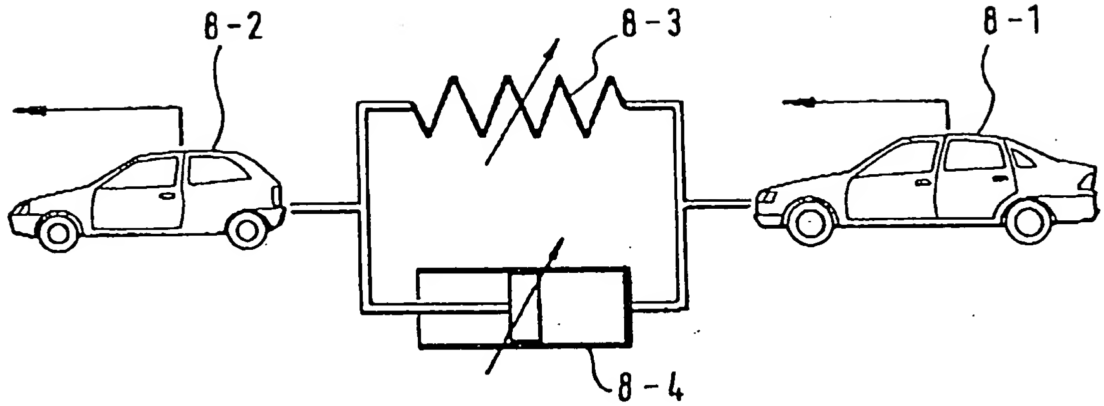


Figure 31

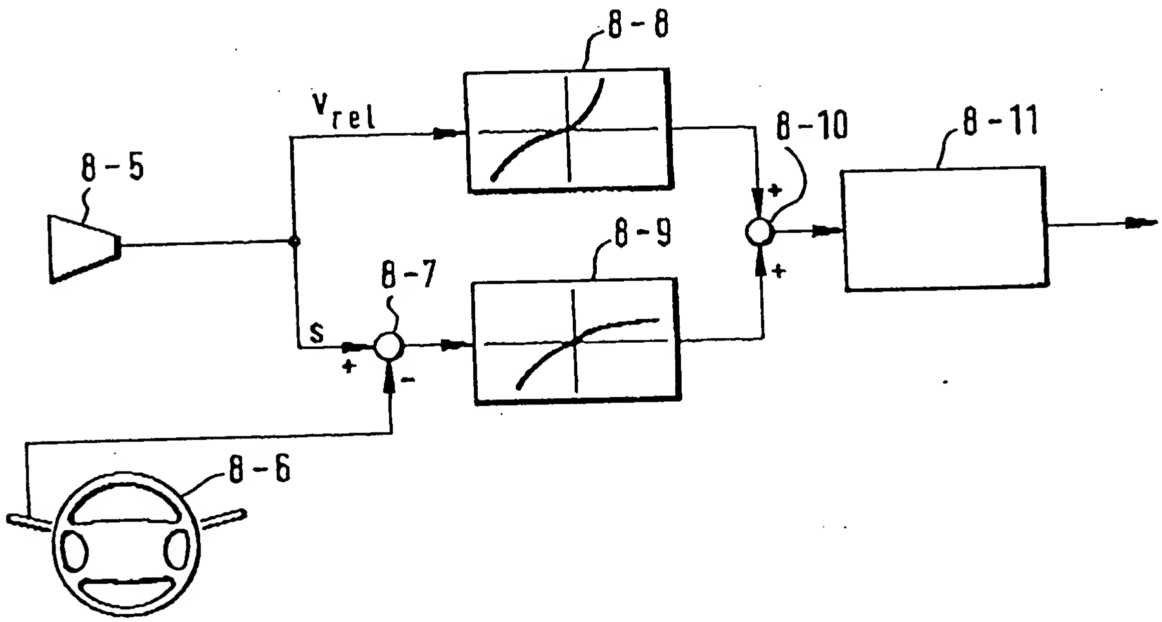


Figure 32

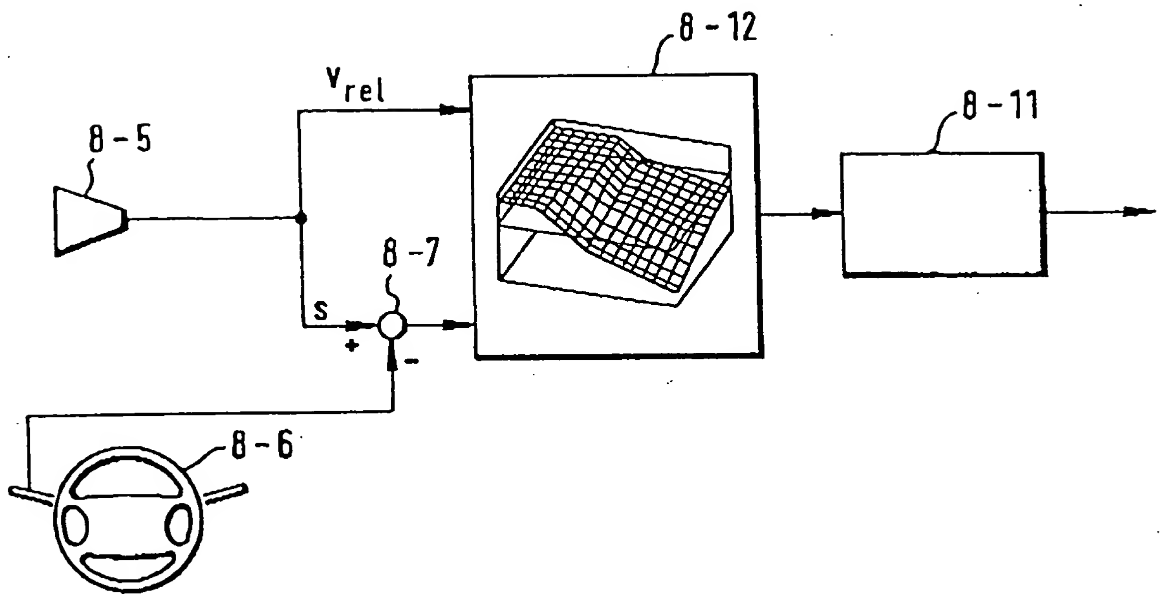
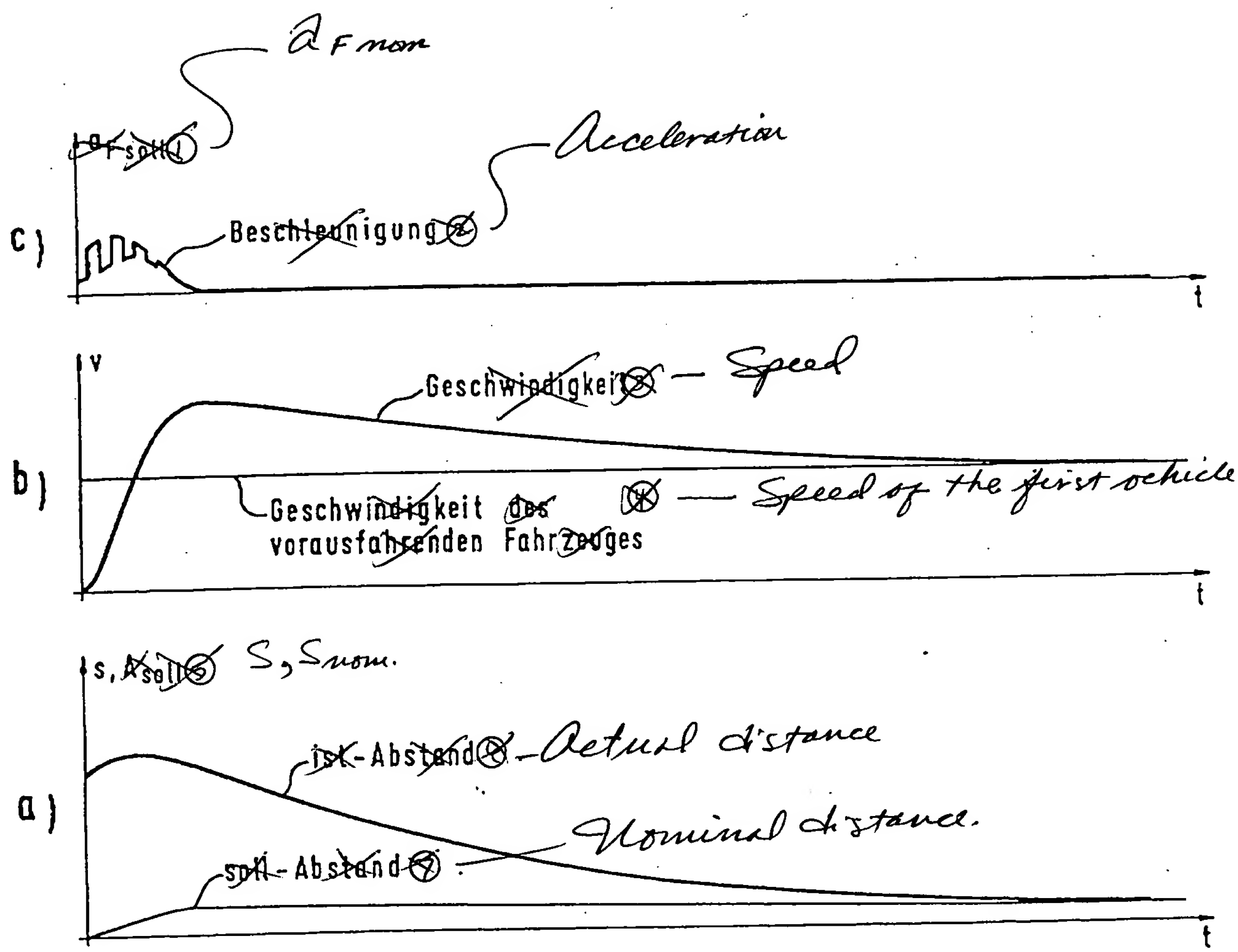


Figure 33



$a_{F\,nom}$
~~$a_{F\,soll}$~~ (1)
Acceleration
~~Beschleunigung~~ (2)
c)
t
v
~~Geschwindigkeit~~ (3) — Speed
b)
~~Geschwindigkeit des vorausfahrenden Fahrzeuges~~ (4) — Speed of the first vehicle
t
~~s, A_{soll}~~ (5) S, $S_{nom.}$
~~ist-Abstand~~ (6) — Actual distance
a)
Nominal distance.
~~soll-Abstand~~ (7)
t

Figure 34

Key: 1 $a_{F\ nom}$
2 Acceleration
3 Speed
4 Speed of the first vehicle
5 S, S_{nom}
6 Actual distance
7 Nominal distance

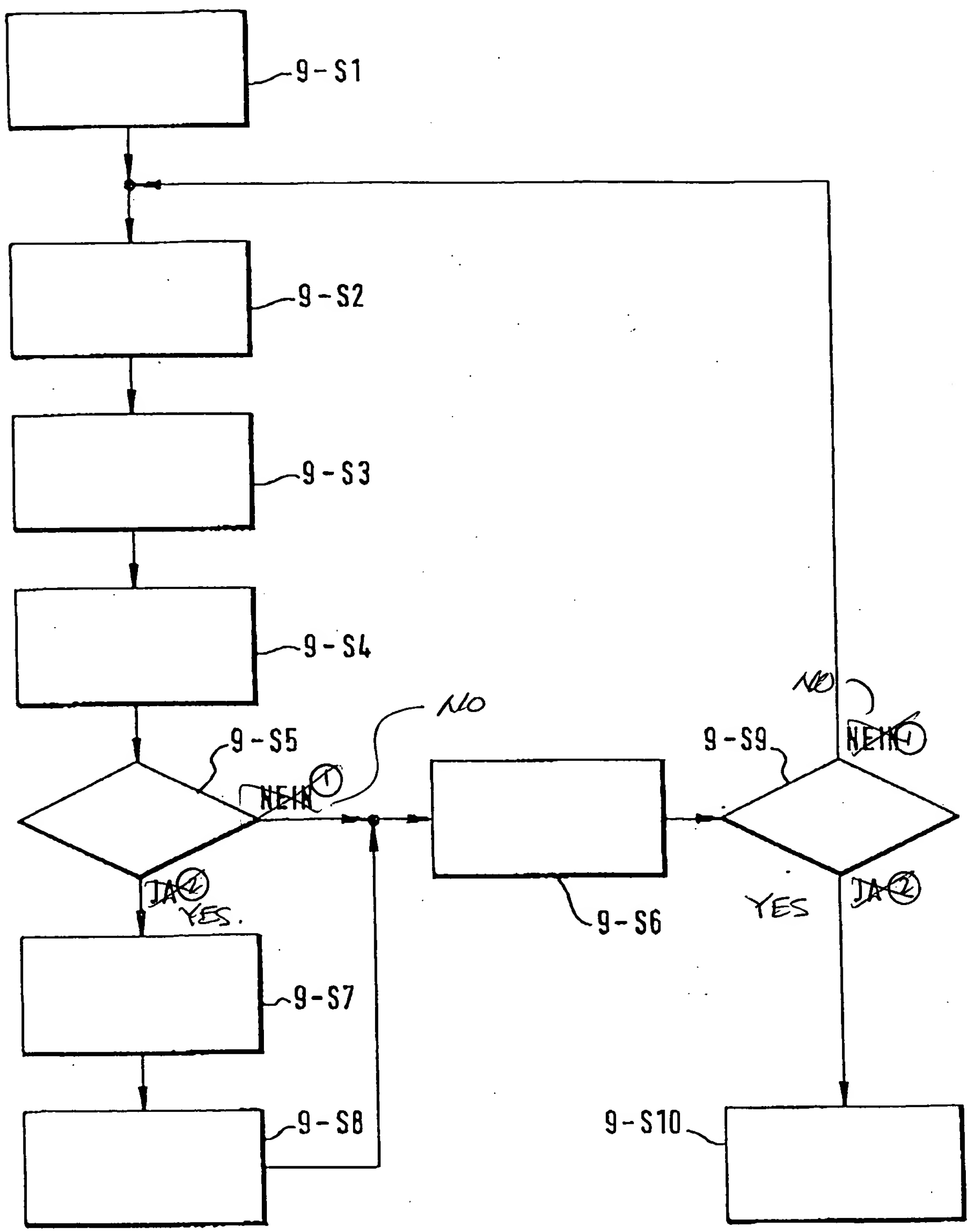

9-S1
9-S2
9-S3
9-S4
9-S5
NEIN
NO
JA
YES.
9-S6
9-S9
NO
NEIN
JA
YES
9-S7
9-S8
9-S10

Figure 35

~~Key: 1 2~~ ~~No Yes~~

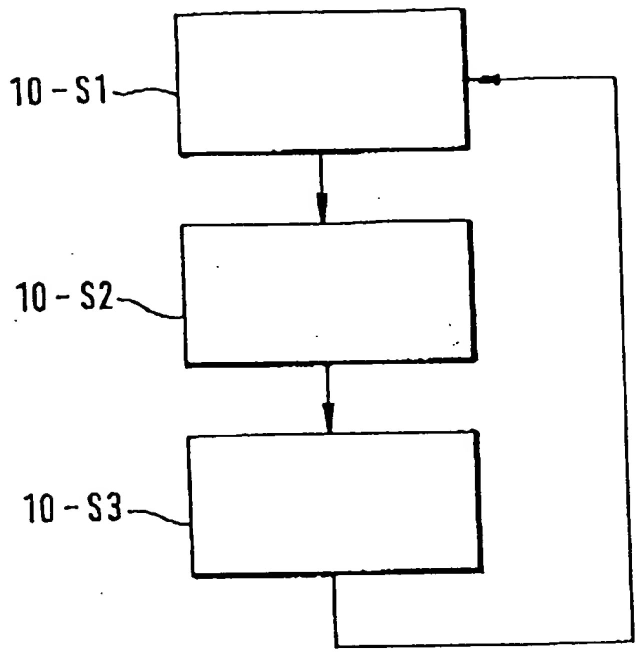


Figure 36

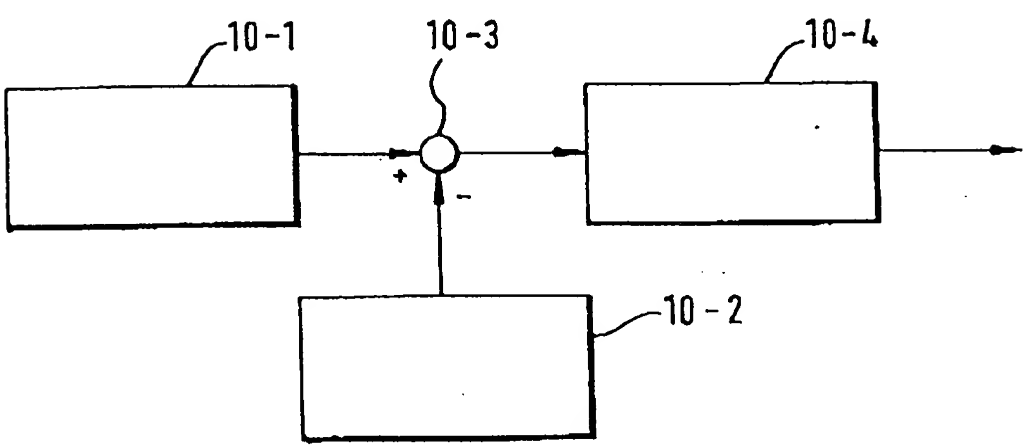


Figure 37